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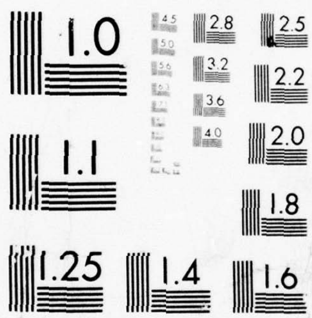


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AN INVESTIGATION OF DUST STORM GENERATION

IN THE SOUTHERN GREAT PLAINS

A Thesis

by

MARSHALL CONRAD POLLARD

Submitted to the Graduate College of
Texas A&M University
in partial fulfillment of the requirement for the degree of

MASTER OF SCIENCE

December 1977

Major Subject: Meteorology

# AN INVESTIGATION OF DUST STORM GENERATION IN THE SOUTHERN GREAT PLAINS

A Thesis

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MARSHALL CONRAD POLLARD

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(Member)



December 1977

| REPORT DOCUMENTATION PAGE | | READ INSTRUCTIONS BEFORE COMPLETING FORM |
|---|---|---|
| 1. REPORT NUMBER<br>14 AFIT-CI-78-46 | 2. GOVT ACCESSION NO. | 3. RECIPIENT'S CATALOG NUMBER |
| 4. TITLE (and Subtitle)<br>6 An Investigation of Dust Storm Generation in the Southern Great Plains | | 5. TYPE OF REPORT & PERIOD COVERED<br>9 Masters Thesis |
| | | 6. PERFORMING ORG. REPORT NUMBER |
| 7. AUTHOR(s)<br>10 Conrad<br>Captain Marshall ~~C.~~ Pollard | | 8. CONTRACT OR GRANT NUMBER(s) |
| 9. PERFORMING ORGANIZATION NAME AND ADDRESS<br>AFIT/CI Student at Texas A&M University, College Station TX | | 10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS |
| 11. CONTROLLING OFFICE NAME AND ADDRESS<br>AFIT/CI<br>WPAFB OH 45433 | | 12. REPORT DATE<br>11 Dec ~~ember~~ 1977 |
| | | 13. NUMBER OF PAGES<br>75 Pages 12 85p. |
| 14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office) | | 15. SECURITY CLASS. (of this report)<br>Unclassified |
| | | 15a. DECLASSIFICATION/DOWNGRADING SCHEDULE |
| 16. DISTRIBUTION STATEMENT (of this Report)<br>Approved for Public Release; Distribution Unlimited | | |
| 17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report) | | |
| 18. SUPPLEMENTARY NOTES<br>JERRAL F. GUESS, Captain, USAF<br>Director of Information, AFIT<br>APPROVED FOR PUBLIC RELEASE AFR 190-17. | | |
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| 20. ABSTRACT (Continue on reverse side if necessary and identify by block number) | | |

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# ABSTRACT

An Investigation of Dust Storm Generation in the Southern Great Plains. (December 1977)

Marshall Conrad Pollard, B.S., University of Utah

Chairman of Advisory Committee: Prof. Walter K. Henry

An investigation of dust storms in the Southern Great Plains was conducted to determine correlations between dust and precipitation, Antecedent Precipitation Index (API), wind, time of occurrence, and dew-point depression. Relationships between blowing dust and characteristics of the Southern Great Plains, agricultural practices, location of source regions, transport mechanisms, and favorable synoptic situations also were considered. Data used in this study consisted of surface observations from 34 Southern Great Plains weather stations during February through May for a 10-yr period (1966-1975).

Results of the analyses showed an insignificant correlation of precipitation amounts prior to a dust storm. Also, dew-point depression was weakly correlated to dust generation. A negative correlation existed between API and the number of stations reporting dust. It was found that wind speed and direction were significantly correlated with occurrences of dust. The greatest frequency of occurrences of dust was between 1800 to 0100 GMT (12:00 to 7:00 PM CST). It was determined that the location of a source region was an important factor for generation of dust.

## ACKNOWLEDGMENTS

I wish to express my appreciation to:

The Air Force Institute of Technology, United States Air Force, for sponsoring and financing my graduate program.

The U.S. Air Force Environmental Technical Applications Center, for providing data for this study.

W. K. Henry, my committee chairman, for his patience, guidance, and support throughout my graduate program, and for valuable and timely assistance in the preparation of this thesis.

Dr. V. E. Moyer and Dr. S. P. Slinker, for their assistance during the final preparation of the manuscript.

Dr. K. C. Brundidge and Dr. G. L. Huebner, for providing the funds necessary to complete the data processing.

Mr. T. J. Reid, who assisted me with programming problems.

My parents, who have encouraged me during my undergraduate and graduate programs.

My wife, Barbara, whose continual patience, sacrifice, and understanding were essential to the completion of my program.

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# 1. INTRODUCTION

## a. General

Monstrous brown clouds of dust whipped and churned by strong winds continue each year to sweep across the sometime drought-stricken Great Plains, thereby causing havoc. Some of the adverse effects of dust storms are reduction to visibility, malfunction of mechanical equipment, and hazards to health.

Reduced visibility greatly affects flying conditions and, to a lesser extent, ground vehicle operations. One extreme example of a flight incident occurred in 1953 at Webb Air Force Base, Texas, when a Beech Bonanza crashed 1370 m from the Operations Building and was not discovered until 24 h later when suspended dust from an intense dust storm subsided. A dust storm in Arizona reduced visibility so low that a 20-car pile-up occurred on a major freeway and resulted in eight deaths and 23 injuries.

Windborne dust also permeates moving mechanical parts and acts as an abrasive agent. Mechancial failures and deterioration of materials are the result. This becomes a significant parameter for military operations in an arid or semiarid climate. Mechanical engine operating equipment such as aircraft, tanks, and generators suffer worn piston rings, scored cylinders, and damaged bearings when operated

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in blowing dust regions. For instance, during World War II, the tanks and vehicles used by General Patton's troops on maneuvers near Desert City had a higher-than-usual rate of engine replacement due to abnormal cylinder wear.

Another adverse effect of blowing dust is the health problems caused by the swirling dust. Eye irritations, runny noses, and coughing are symptoms for many persons exposed to windborne dust. The author attests to the health problems associated with blowing dust as he experienced several major dust storms while stationed at Dyess Air Force Base, Texas. On several occasions during the spring months, huge clouds of blowing dust swept through north central Texas and left the author with a runny nose and coughing spells for several days after most of the dust settled. The blowing dust also filters through windows, electrical outlets, and any crevices in buildings, thus leaving an unsanitary layer of topsoil in buildings.

Soil scientists are concerned with another serious problem associated with dust storms -- soil erosion. They point out that not even rich, deep topsoil can sustain a loss of more than 5 tons an acre per year without hurting productivity. During the week of 20 February 1977, strong post-frontal winds of up to 40 m $s^{-1}$ in eastern Colorado scooped up drought-dry topsoil and scalped some 5 tons from each acre of land during the 24-h dust storm. Gillette <u>et al</u>. (1973) computed that the loss of soil for the average eroding field during a large dust storm in the Southern Great

Plains on 14 April 1972 was a total of 9.2 tons per acre for the 9-h storm. The loss of silt and clay with this storm reduced the available soil water from 0.088 to 0.078 cm of water per cm of soil, or the water-holding capacity of the soil was reduced 2,720 gal per acre. Erosion losses nationally have been estimated at about 9 to 12 tons an acre per year (Carter, 1977). New topsoil forms at a rate of about 1.5 tons an acre per year under normal farming. In 1975 the Council for Agricultural Science and Technology (CAST) reported on conditions which could trigger another dust bowl in the Great Plains. The CAST report stated that farmers are reportedly changing from wheat-fallow crop rotations to continuous planting of wheat. When downy bromegrass is plowed under, the soil surfaces are left bare of harvest residues that help hold the soil in place. And with the growth of overseas markets and rising commodity prices, farmers have been putting as much of their land into production as possible. The massive dust storm the week of 20 February 1977 evidences the continuing poor conservation practices.

Despite the fact that dust storms are a recurring weather phenomenon with adverse effects, little research has been done to investigate their generation, intensity, and prediction. It is the purpose of this study to examine the nature and generation of dust storms in the Southern Great Plains and to analyze correlations between blowing dust and relative parameters, such as wind and precipitation.

b. Review of the literature

Dust storms have continued to plague drought regions of the world. The Great Plains region of the United States is the area that has the greatest damage. In 1895 a major dust storm caused the loss of 20% of the cattle in eastern Colorado (Idso, 1973). Soil Conservation Service (1961) reported that during a major drought of the 1930s dust storms removed from 5 to 31 cm of topsoil from many fields in the Southern Great Plains. The storms were so devastating as to drive thousands of people from their farmsteads, and during this period the nation's journalists named this region the Dust Bowl. A dust storm on 14 April 1935 engulfed Stratford, Texas. Many deaths from suffocation occurred despite protection of dustmasks. Warn (1935) pointed out that at the end of 1952 drought and crop failure were estimated to have rendered over six million acres of land in Texas and Oklahoma susceptible to wind erosion. It was estimated by Pimentel et al. (1976) that a billion tons of soil are currently being lost through wind erosion each year in the United States. The control of wind erosion has been left to the farmer, who may use such conservation methods as tillage, contour plowing, crop rotation, shelterbelts, and leaving harvest residues in an attempt to reduce erosion.

The amount of damage resulting from a dust storm depends largely upon its size which is dependent upon associated meteorological phenomena. The range is from small

localized dust storms which occur with micrometeorological phenomena such as whirlwinds and thunderstorms, to synoptic features, such as squall lines, fronts, and mesocyclones. Barenblatt and Golitsyn (1974) stated that dust storms seldom exceed a size of several hundred kilometers; however, with improved satellite imagery, extensive dust storm coverage has been views from space. Shenk and Curran (1974) reported that large dust storms migrate from the Sahara Desert to the Atlantic Ocean. Nimbus 4 satellite images taken between 20 and 23 April 1974 showed a large dust storm spreading from northwest Africa out over the Atlantic. Covalt (1977) displays a satellite photograph from NOAA-5 depicting dust movement over the Gulf of Mexico on 24 February 1977. This dust storm is believed to be the largest ever observed by satellite over the United States. It spread from the Southern Great Plains eastward to the Atlantic Ocean and southeastward over the Gulf of Mexico.

Research concentrating on prediction of dust storm occurrence in the United States has been mainly in the form of local studies. An objective forecast study of blowing dust at Amarillo Air Force Base, Texas (1956), pointed out that synoptic conditions producing strong winds and accompanying blowing dust result from leeside troughs intensifying to the west and northwest, polar front passages with strong postfrontal northwesterly winds, or forceful downrush gusts of thunderstorms. Elser (1959) presents a good case of thunderstorm-generated blowing dust

at El Paso, Texas. Try (1963) suggests that probable predictors of blowing dust in the area of Luke Air Force Base, Arizona, are speed and direction of the surface wind, soil condition as affected by rainfall and agriculture, and time of year of greatest occurrence. His results were not favorable because of a lack of a sufficient number of cases. He was unable to find a good correlation with respect to greatest frequency during any month of the year. Further, he could not correlate continuous rainfall over the station within the previous 48 to 72 h and visibility restrictions from suspended dust. For the area of Big Spring, Texas, Fryrear and Randel (1972) devised a method of predicting the number of days with blowing dust for the following year. Edson _et al_. (1954) related soil moisture with dust storms occurring at Webb Air Force Base, Texas. They found evidence that a relationship between soil moisture and frequency of dust storms does exist in west Texas. The greatest frequency of dust storms was associated with the least amount of annual precipitation. In a wind and dust study for Lubbock, Texas, Pecille (1973) used 87,660 observations of wind velocity and dust occurrence for a 10-yr period (1951-60) to show a positive correlation. Wind rose data showed that the south through west-northwest sector accounted for 49 percent of the total wind observations; however, 68 percent of the time during dust reportings, winds were from this sector. These local

studies are much more specific on prediction and causes of dust storms than the regional area studies.

Regional area studies covering large regions, however, are valuable in identifying significant areas affected by dust and possible parameters relating to dust storm generation. Orgill and Sehmel (1976) associated the frequency and diurnal variation of dust storms in regions of the United States. Using tabulations for 343 weather stations, they determined annual percentage frequency of dusty hours based on hourly observations of dust, blowing dust, and sand when prevailing visibilities were less than 11 km. The highest annual frequency of dust (1-3%) in the nation is located in the Southern Great Plains, and the maximum frequency of suspended dust occurs during the months of March, April, and May. For the southwestern United States, Meigs (1963) related critical pick-up velocity for sand and dust with degree of surface coherency and different grain sizes. His results showed that winds of 8.9 m $s^{-1}$ would initiate dust and sand movement in sandy terrain and 8.9 to 11.2 m $s^{-1}$ will set fine material on desert flats in motion. He remarked that disturbance of the surface by natural or artificial means will lower critical pick-up velocities by as much as 2.2 m $s^{-1}$. Brown et al. (1968) found a positive correlation between dust deposition and average monthly winds for locations east of the Rocky Mountains.

In spite of the discomfort and economic loss caused by dust storms, the problems of forecasting these phenomena have not been addressed by the meteorological community. This is indicated by the lack of literature in the American Meteorological Society journals, geophysical journals, and other scientific and nonscientific publications. Barenblatt and Golitsyn (1974) declared that information stored on dust storms is only of a descriptive nature and there are practically no reliable measurements of vertical profiles for wind and dust concentration.

### c. Characteristics of the Southern Great Plains

Before studying and analyzing dust storms in the Southern Great Plains, it is necessary to understand the characteristics of this region. The Great Plains comprise a large area of the central United States (Fig. 1). Geologic landforms in this region consist of flat areas with rolling hills, and are a result of Paleozoic and Mesozoic formations being warped and folded. These folded formations were planed by erosion in early and middle Tertiary time. In late Tertiary time the eroded surface was covered by gravels washed eastward from the Rocky Mountains. The topographic relief of the Great Plains is one of gentle rising westward for 800 km from about 600 m near the 100th meridian to about 1500 m at the foot of the Rocky Mountains (Fig. 2).

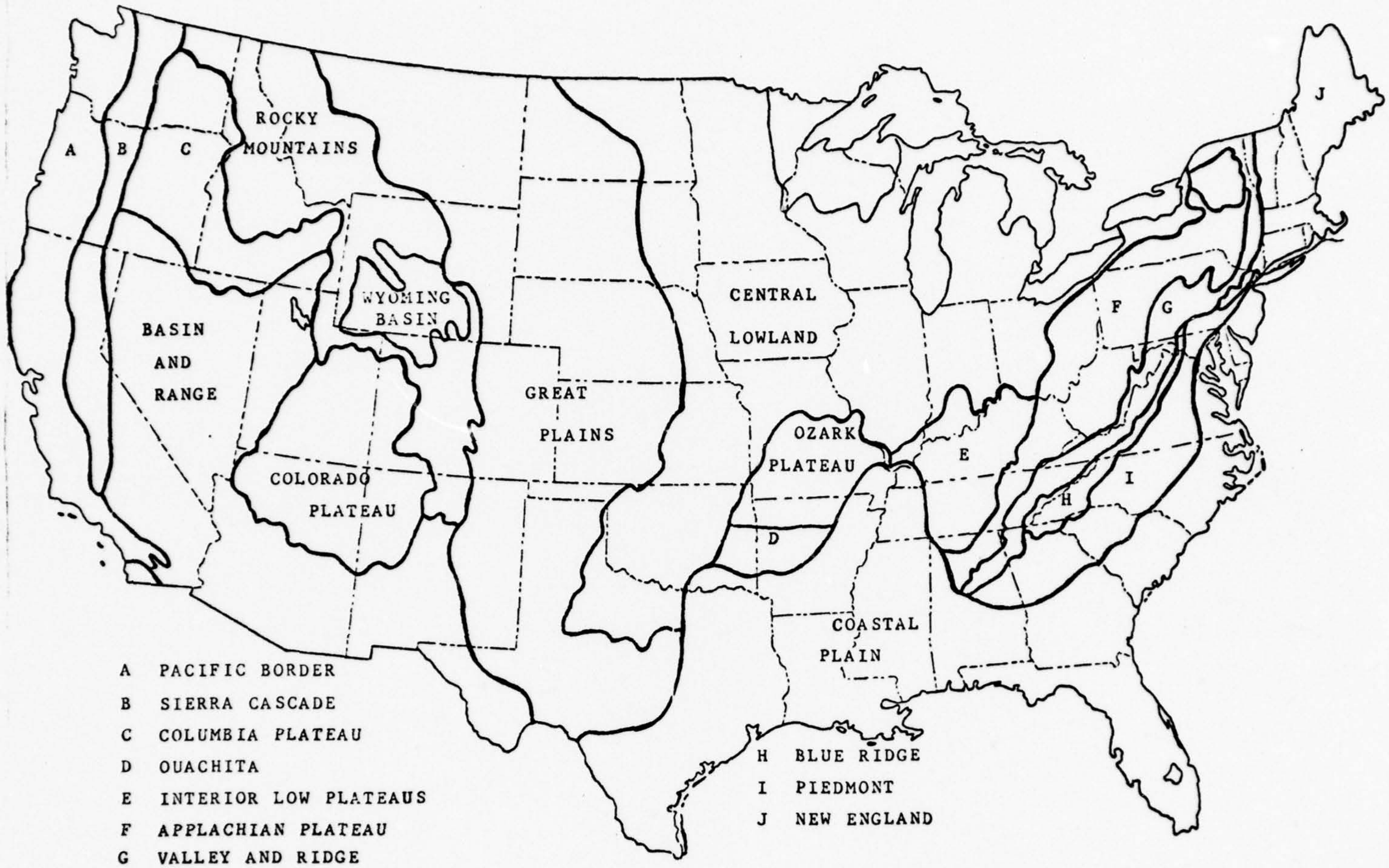


Fig. 1. Physiographic regions of the United States and their dominant landforms (after Hunt, 1967).

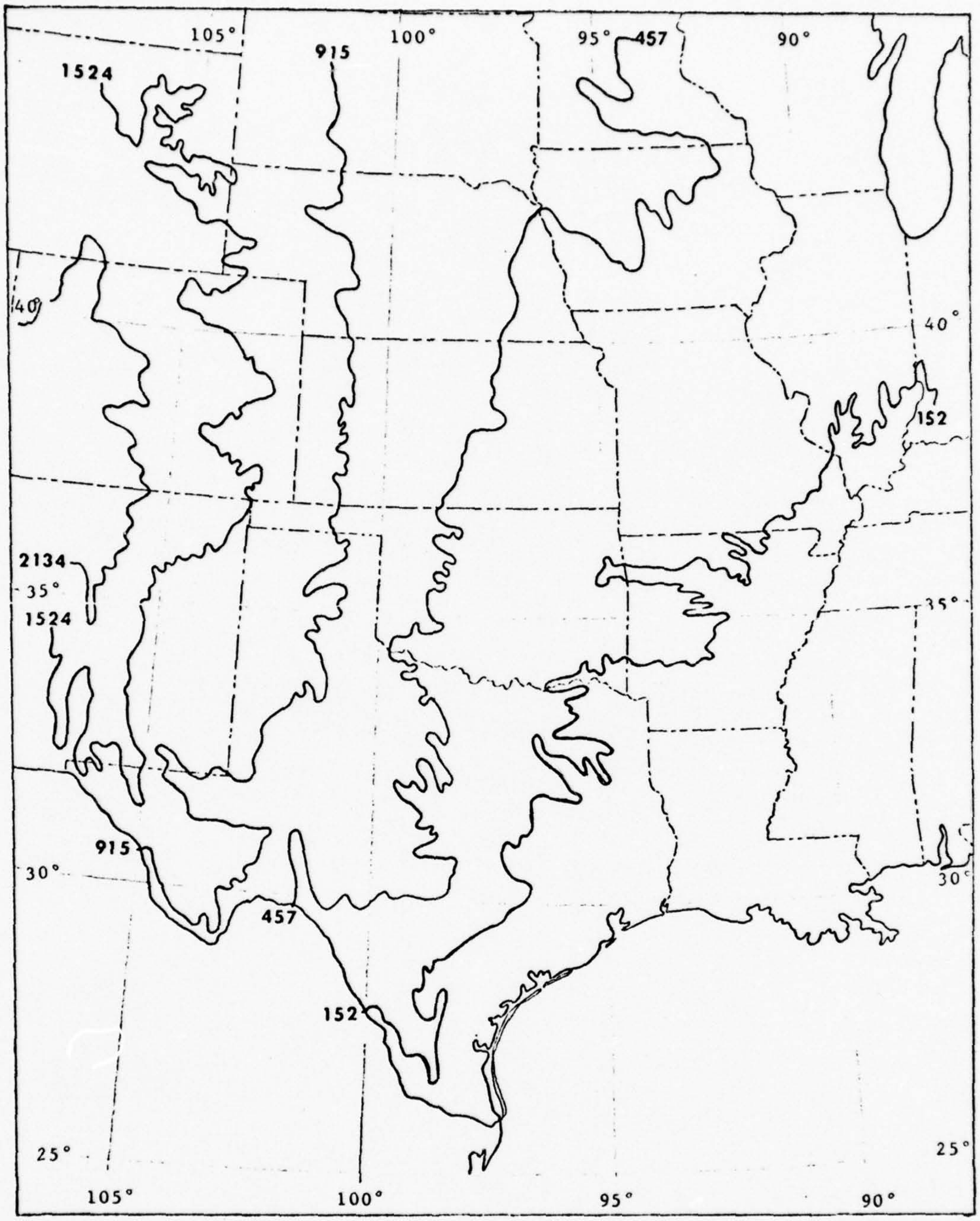


Fig. 2. Topographic relief of the central United States (isopleths are expressed in m).

Climatically the Great Plains are a semiarid region which is moist part of the year and dry for periods amounting to more than three months per year. It is also considered part of the North American Desert (Fig. 3). Many climatologists believe that the desert borders are not permanent, but expand and contract from time to time (Fig. 4). Annual precipitation amounts shown in Fig. 5 vary from approximately 90 cm (36 in.) in the southeastern borders to 30 cm (12 in.) in the southwestern borders.

Vegetation in the Great Plains consists mainly of short grasses westward of the 100th meridian and 50-cm (20-in.) rainfall line with desert shrub being dominant west of the 40-cm (15-in.) line, and tall grasses and broadleaf forest east of the 50-cm line (Fig. 6).

Zoned, or zonal, soil profiles correspond closely to the climate and vegetation zones in which they are found (Fig. 7). Soils of the Southern Great Plains consist of Prairie, Chernozem, Chestnut, and Brown soils from east to west, respectively. Soils are progressively darker eastward from the Rocky Mountains, thereby indicating richer soils due to more vegetation decaying and adding to soil enrichment. The mineral particles comprising a soil are a mixture of clay, silt, and sand, and a soil is described according to the amount of these particles it contains (Fig. 8). Soil particles range in size from the fine clays to the coarse sands (Table 1). Some soils are

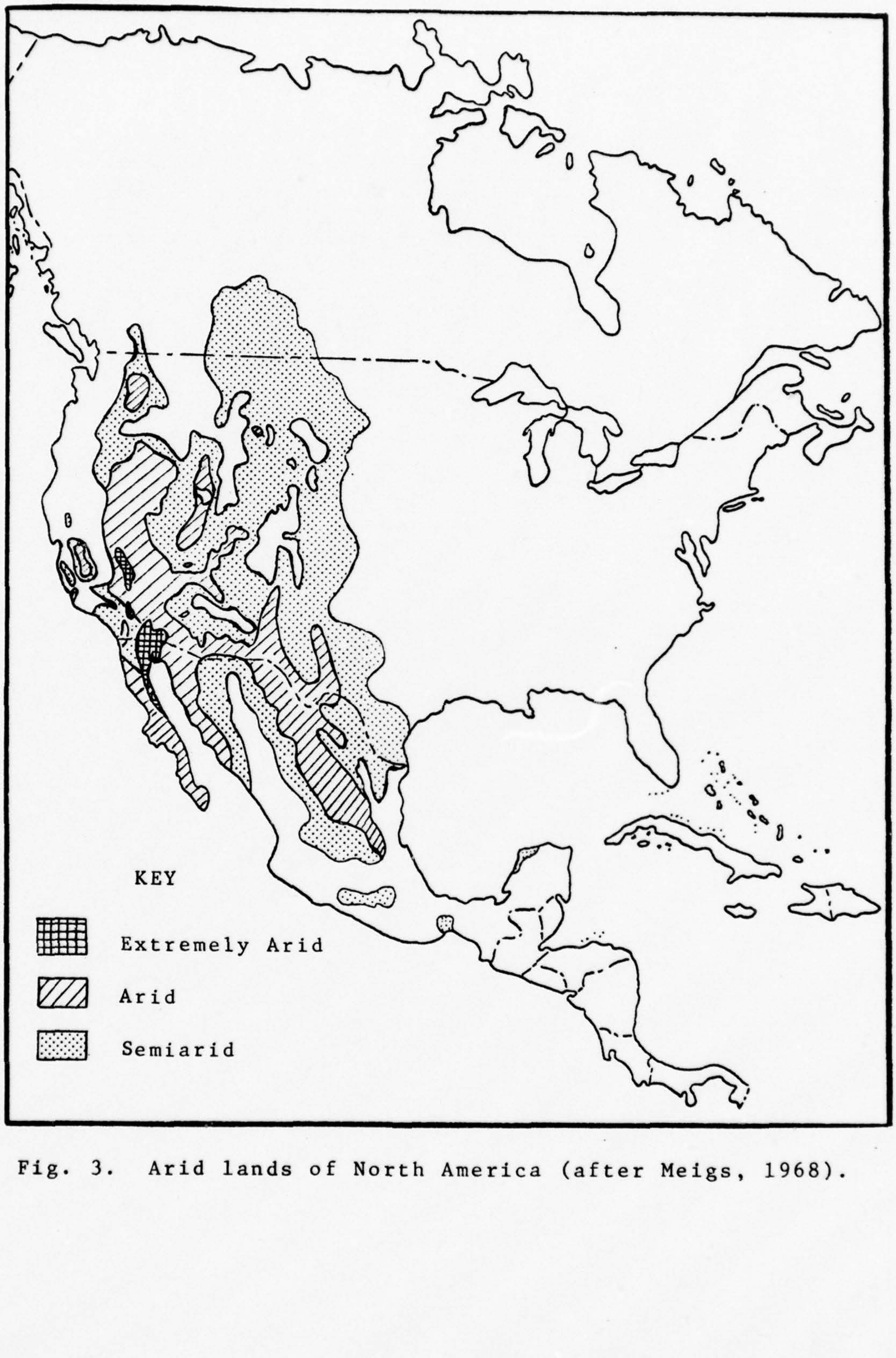


Fig. 3. Arid lands of North America (after Meigs, 1968).

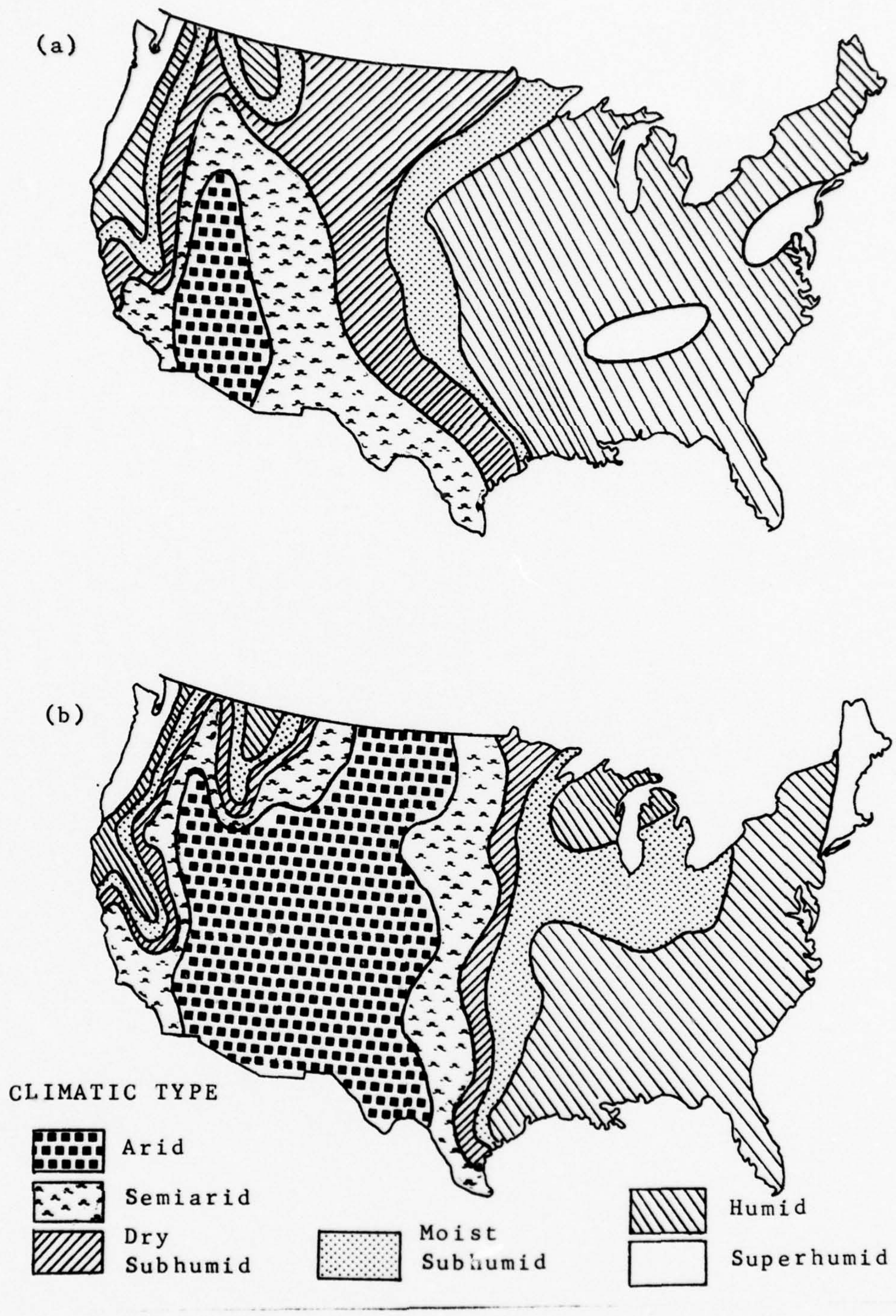


Fig. 4. Generalized distribution of climatic types in the United States for (a) the wet year of 1915 and (b) the dry year 1934 (after Thornthwaite, 1941). [Note the expansion of the arid area for 1934.]

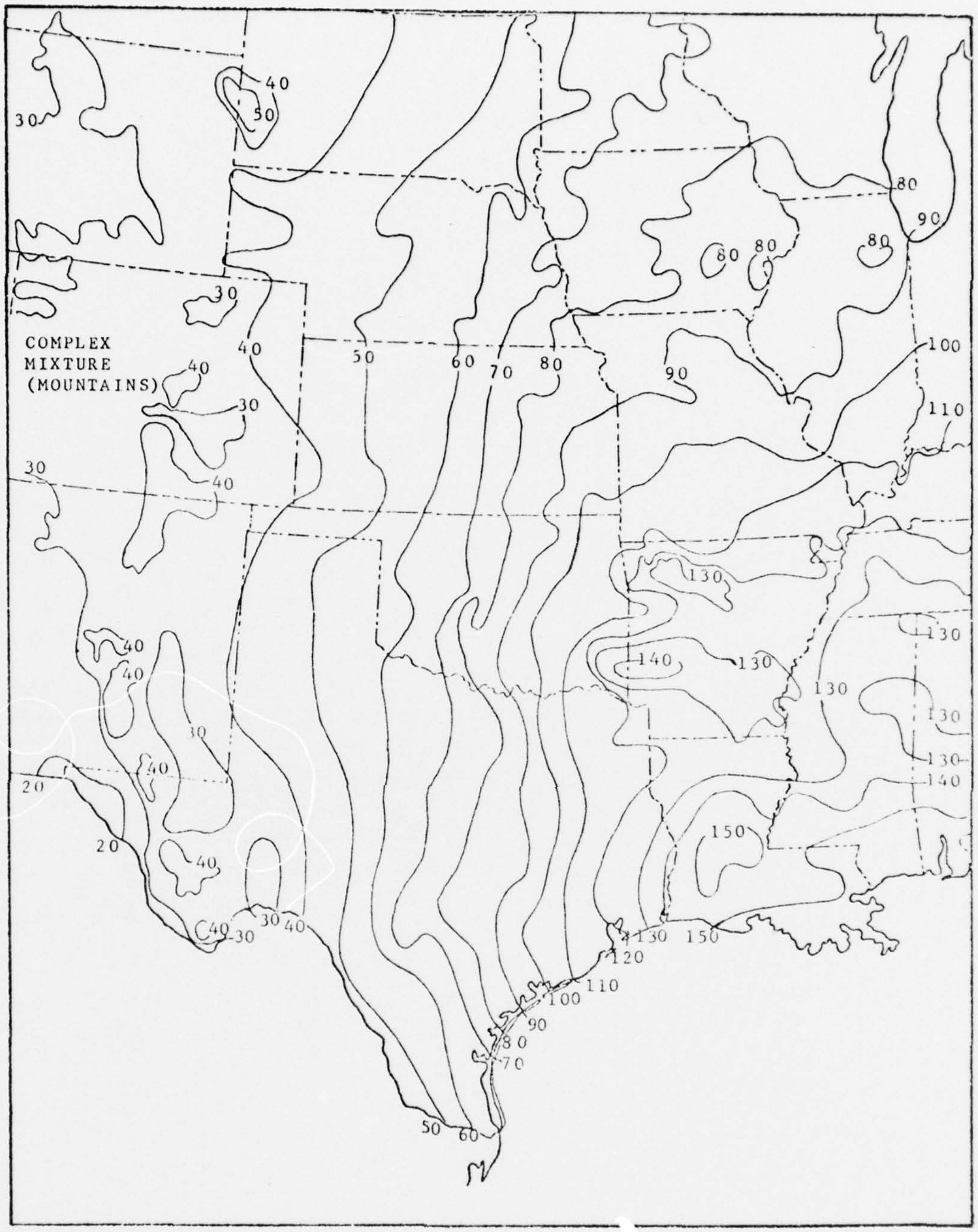


Fig. 5. Mean annual precipitation (in cm) for south central United States (adapted from Environmental Data Service, 1968).

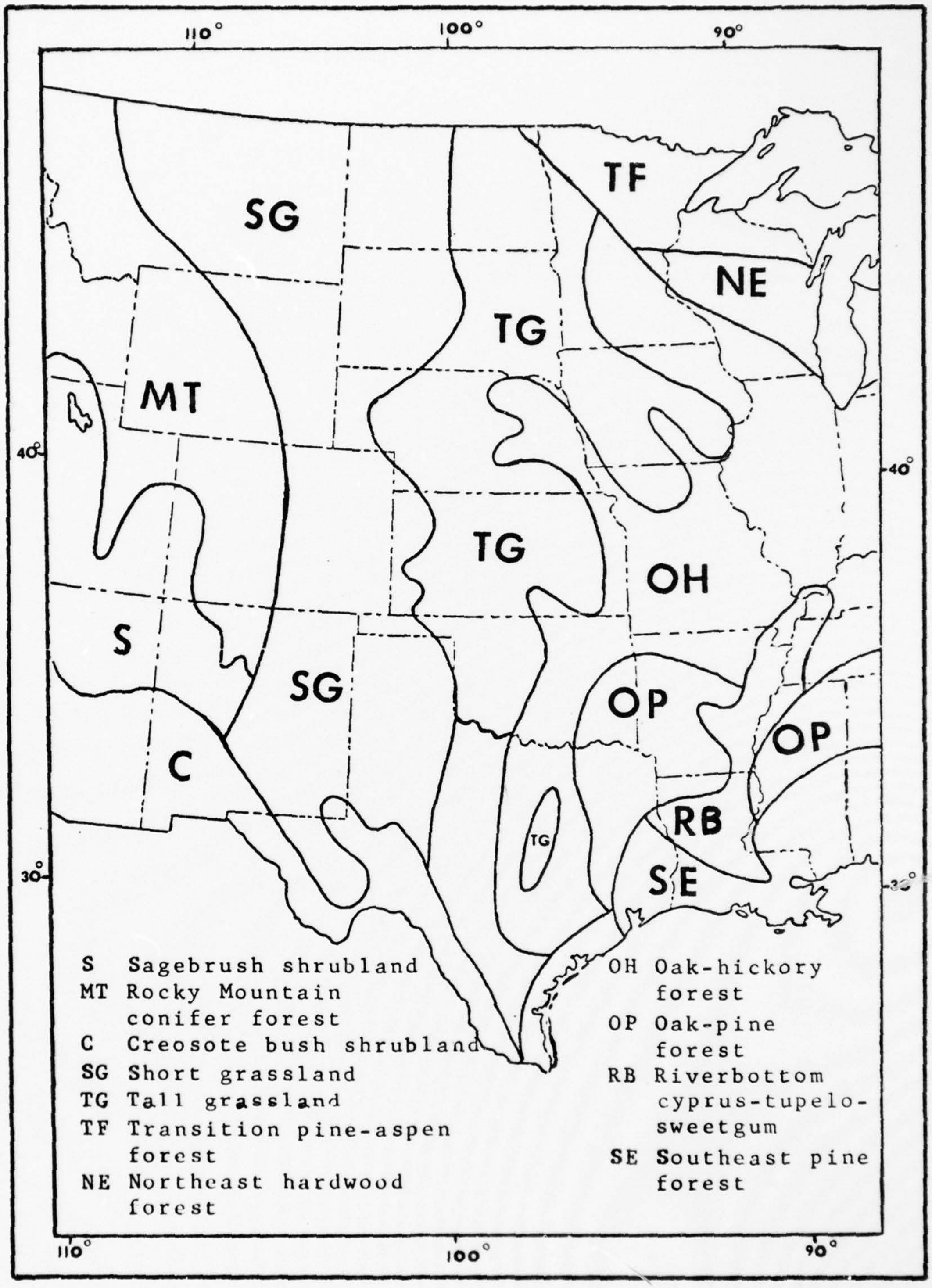


Fig. 6. Natural vegetation in central United States (after Hunt, 1972).

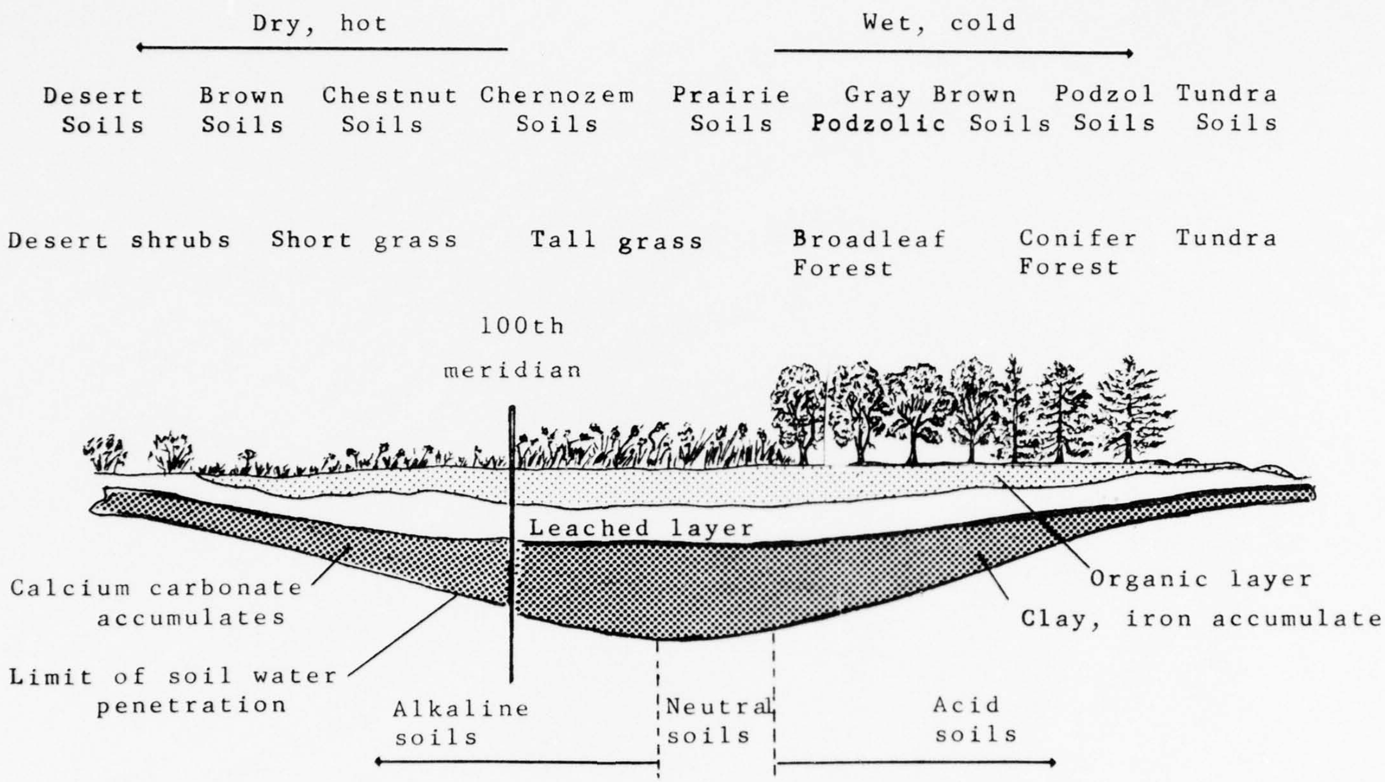


Fig. 7. Transect illustrating changes is soil profiles that accompany changes in vegetation and climate between the tundra in northeastern Canada and the deserts in southwestern United States (after Hunt, 1972).

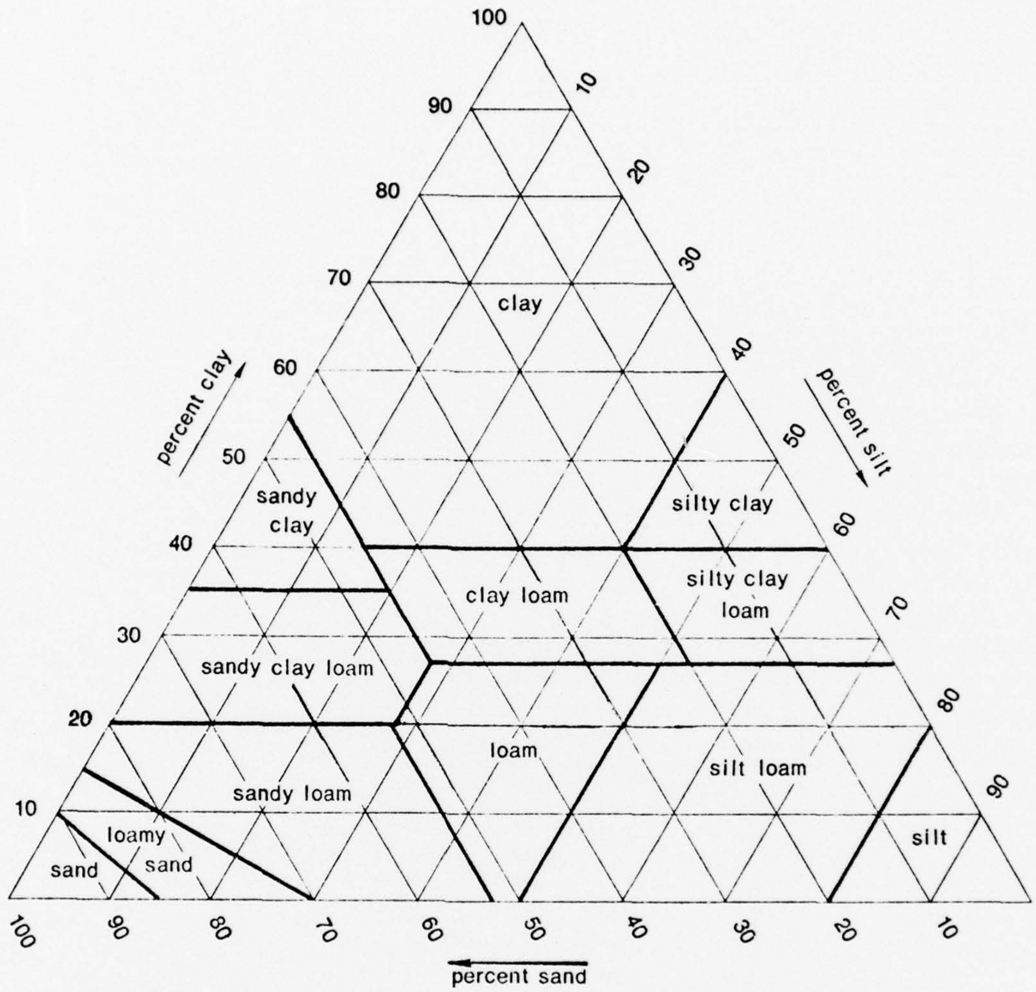


Fig. 8. Soil texture classes--proportion of sand, silt, and clay (after USDA, 1951).

TABLE 1. Scale describing grain sizes of surface deposits and soils (after USDA, 1951).

| Name of fraction | Diameters (mm) |
| --- | --- |
| Very coarse sand | 2.0 - 1.0 |
| Coarse sand | 1.0 - 0.5 |
| Medium sand | 0.5 - 0.25 |
| Fine sand | 0.25 - 0.10 |
| Very fine sand | 0.10 - 0.05 |
| Silt | 0.05 - 0.002 |
| Clay | below 0.002 |

poorly developed and are referred to as Azonal Soils or surface deposits. Most of the deposits are transported by water, wind, or ice and are of many different ages. Much of the central United States is blanketed with loess, a deposit of silt that originated as wind-blown dust (Fig. 9). It can be seen that in northwestern Texas, western Oklahoma, eastern Colorado, and western Nebraska there is widespread coverage of wind-deposited silt and sand. Sandy soils of the plains result from selective removal by the wind as well as from wind deposits. The wind acts as a fanning mill on grain, removing only the fine and light materials. This sorting action over a period of years leaves the soil coarser in texture at the surface and some of the surface becomes covered with sand dunes.

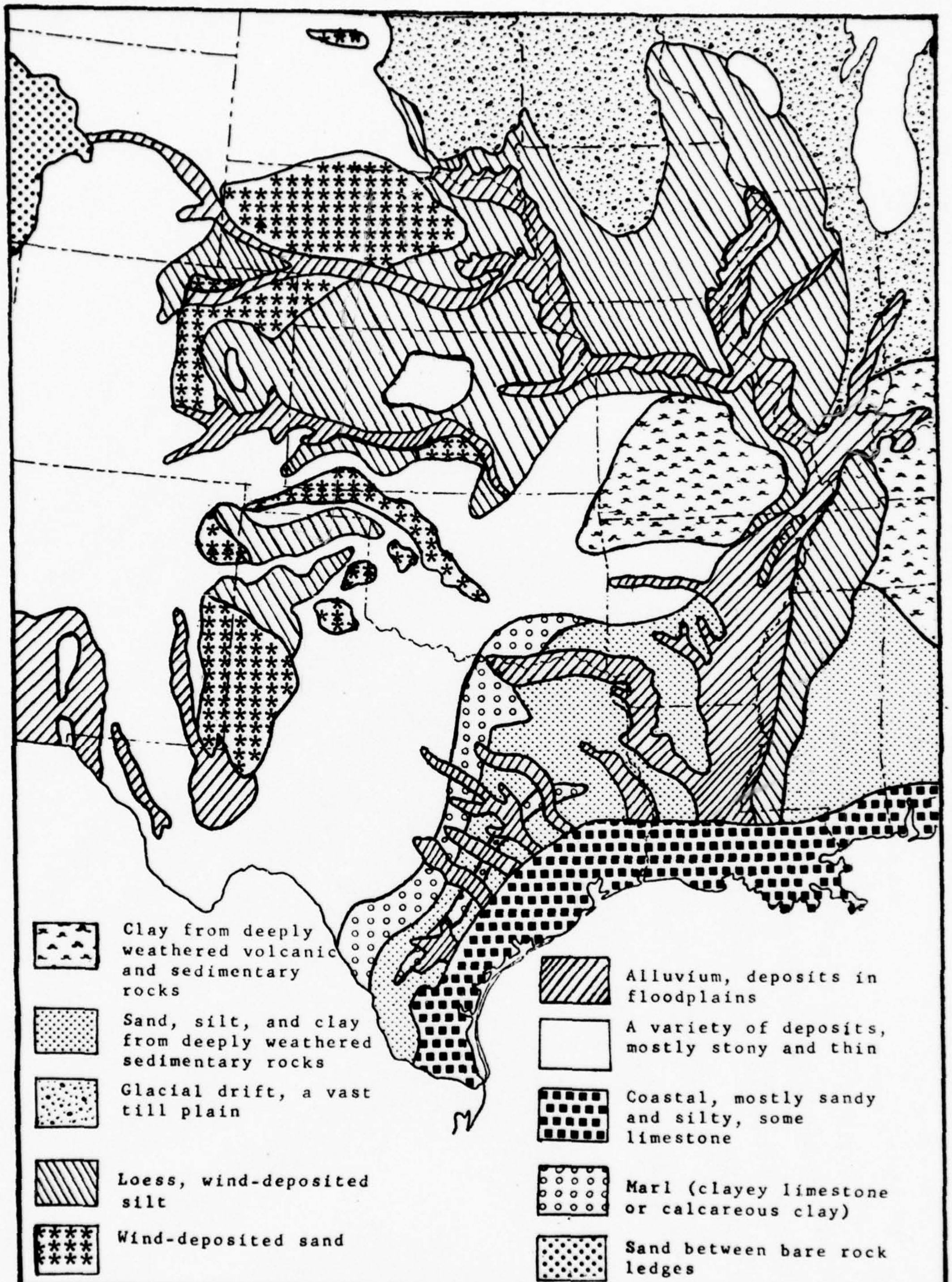


Fig. 9. Surface deposits in central United States (after Hunt, 1967).

Loess and sandy soils provide a source region for blowing dust in the Southern Great Plains.

In the Department of Agriculture classification system, Class I land is defined as soil that can be farmed without any special provisions to prevent it from washing or blowing. The range extends to Class IV, which is soil that needs extremely careful handling and protection from erosion. In the southern plains, flat, hard land is considered Class IV when annual rainfall is less than 46 cm (18 in.). Sandy lands are never better than Class IV. Finnell (1954) pointed out that the chief contribution to blowing dust in the southern plains comes from Class IV soils. The 50-cm annual isohyet and sandy areas depicted in Figs. 5 and 9 appear to agree well with this fact.

Also adding to the problem of blowing dust are the high evaporation rates that occur in the southern plains (Fig. 10). High evaporation steals much of the moisture needed for crops and plant cover which provide some protection from the wind.

When the characteristics of the Southern Great Plains are combined, we find that it is a semiarid-to-arid area of irregular low to high plains in south central United States, and is covered mainly with grasses and surface deposits of sand, loess, and silt. These characteristics are favorable for blowing dust when high winds are produced by some meteorological situations; thus a dust storm may be

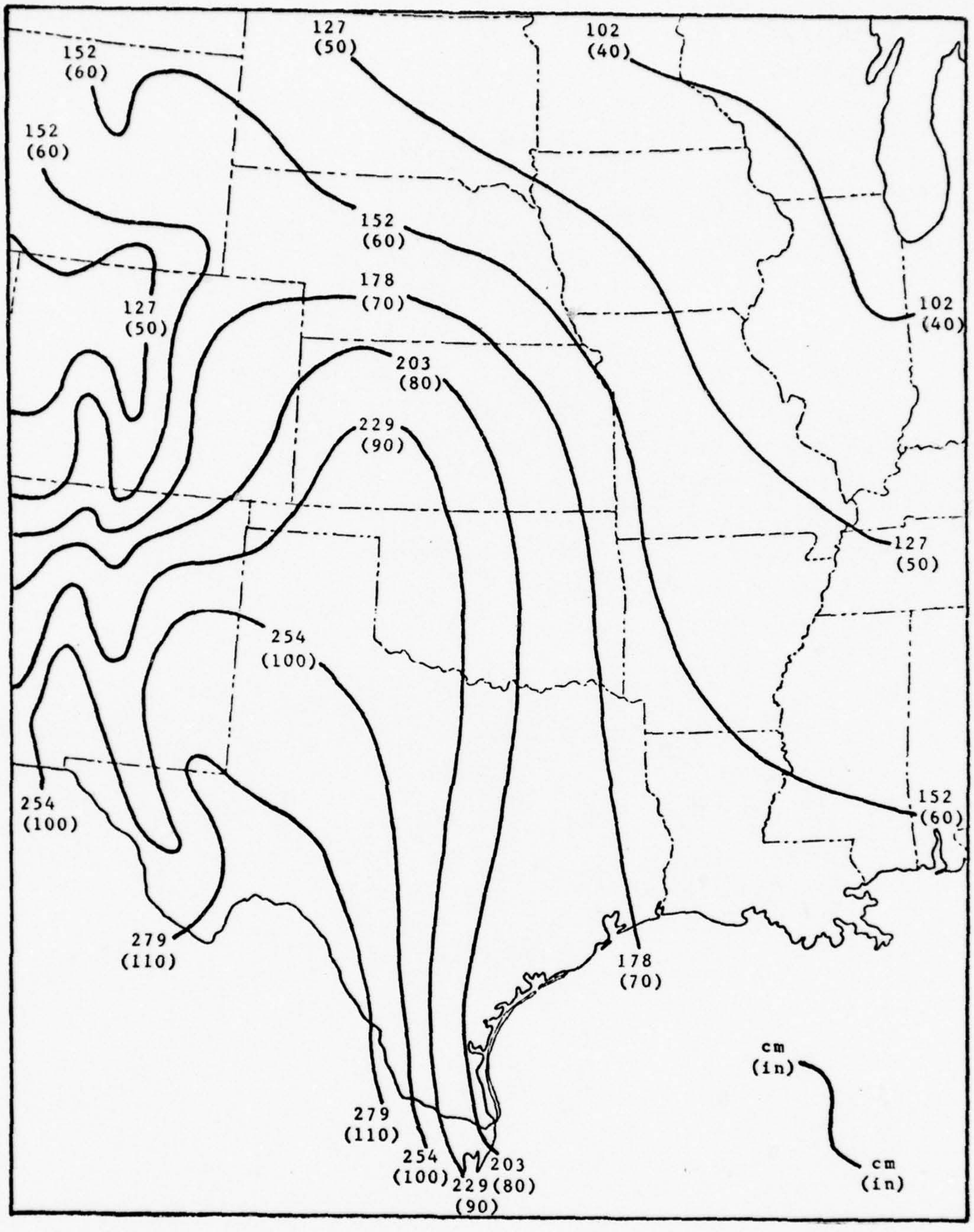


Fig. 10. Mean annual Class A pan evaporation in south central United States (adapted from Environmental Data Service, 1968). [Class A pan evaporation is defined as the measured water loss from a metal pan 1.2 m (4 ft) in diameter by 25.4 cm (10 in.) deep and set very close to the ground.]

generated. Fig. 11 shows that the highest annual frequency of dust occurrences is in northwestern Texas.

Based on the fact that the greatest frequency of blowing dust occurs in the Southern Great Plains, this study will focus on this region (Fig. 12). The time frame to be used will cover February through May for a 10-yr period (1966-75).

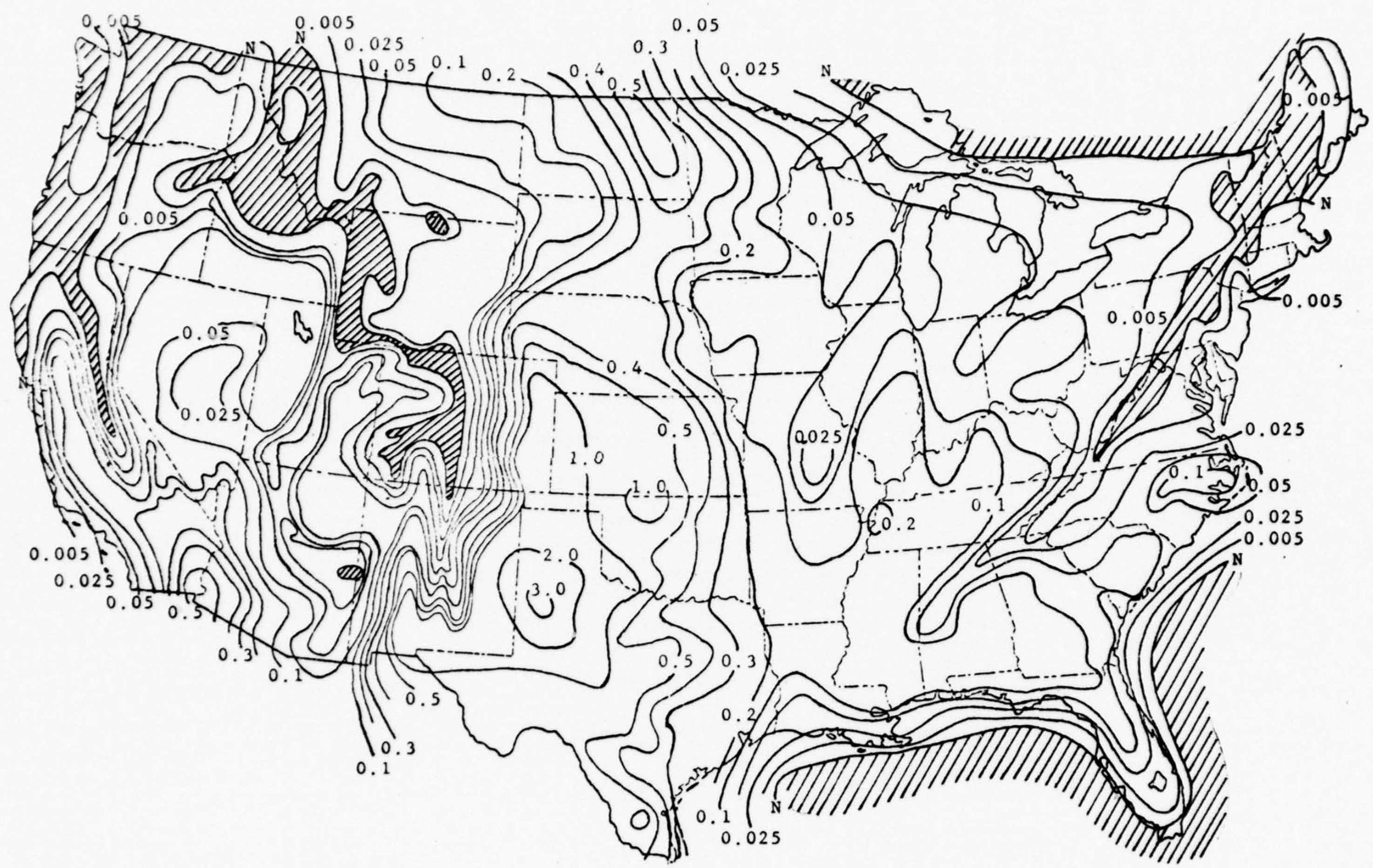


Fig. 11. Annual percent frequency of dusty hours based on hourly observations from 343 weather stations that recorded dust and blowing dust when prevailing visibility was less than 11 km. Hatched areas (N) represent no observations of dust (after Orgill and Sehmel, 1976).

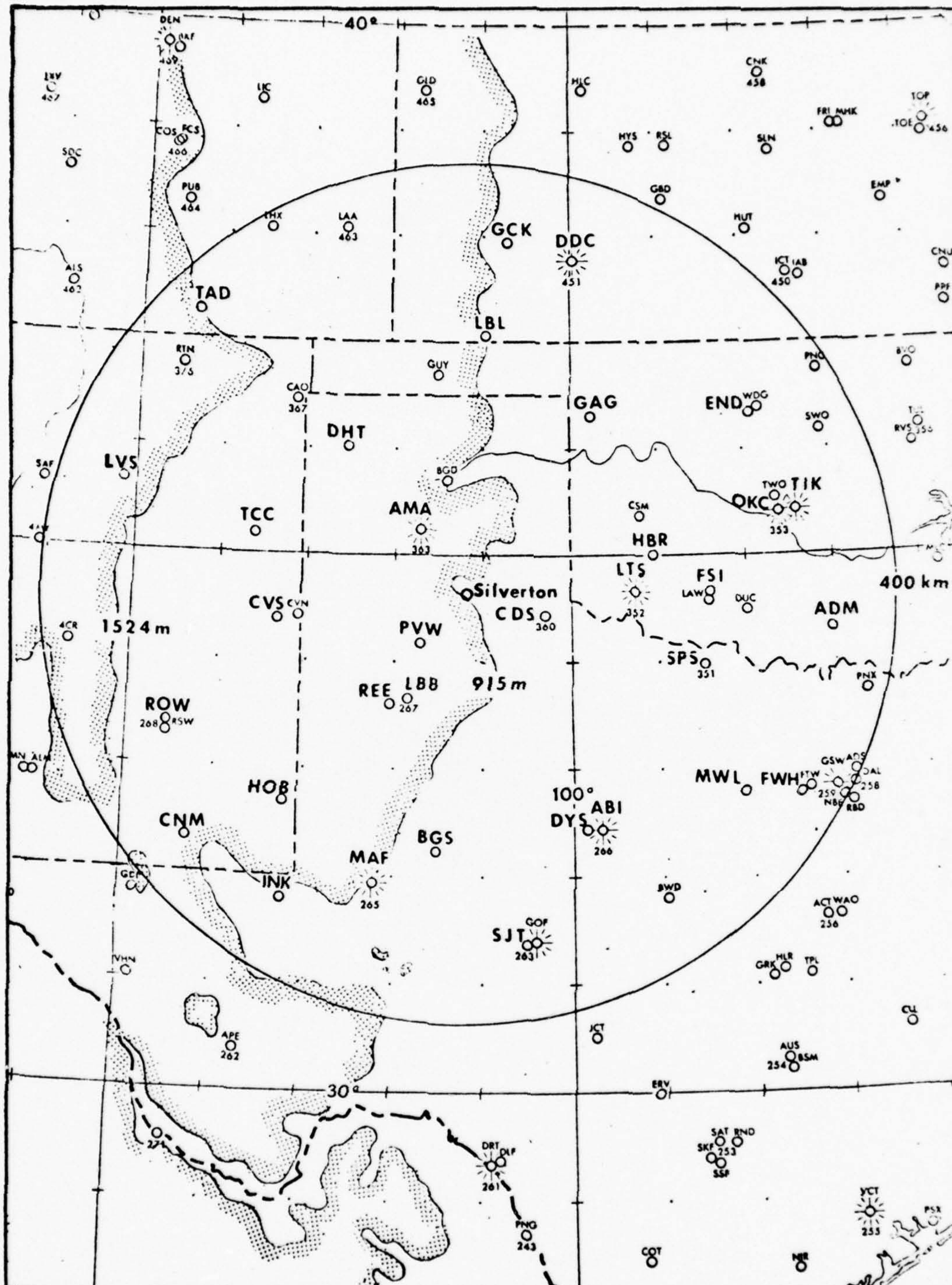


Fig. 12. General area of study. The circle of radius of 400 km centered on Silverton, Texas, encloses the area and stations considered in this study.

## 2. FAVORABLE SYNOPTIC SITUATIONS

### a. General

Dust storm generation is a function of meteorological phenomena, namely strong winds and periods of low precipitation and high evaporation. Other parameters such as wind direction, precipitation type, time of day, and time of year also are significant. Dust storm intensity is primarily a function of wind velocity and duration; however, parameters such as soil condition, source regions for dust, and agricultural practices are important and should be considered.

The prediction of dust storm generation is a complex problem and is interrelated with other meteorological phenomena. The synoptic situations most favorable for strong winds and resulting dust storm generation are squall lines and fronts, cyclones with steep pressure gradients, and on a smaller scale, thunderstorms and whirlwinds.

### b. Squall lines and fronts

The glossary of meteorology defines a squall line as any non-frontal line or narrow band of active thunderstorms. Miller (1967) extends this definition further by stating that a squall line is any line of thunderstorms not readily circumnavigable, regardless of whether it is or is not associated with a front or wind shift. Strong downdrafts from the squall line thunderstorms spread

laterally near the ground as a cold air mass to form the pseudo-cold front or gust front. These gust fronts with their associated strong wind provide an impetus for generating dust storms when other criteria are favorable, e.g., aridity and little soil cover of the locale.

The characteristics of fronts are described in numerous meteorological texts. Established conditions of well developed Pacific fronts and polar cold fronts are the associated wind shifts, wind speed increases, and gustiness. Residents living in the central United States are certainly aware of Canadian generated polar cold fronts, referred to as "blue northers." These cold fronts advance to south central United States during fall and early winter and generate dust storms. They are then called "black northers" or "dusters."

In spring months well organized Pacific cold fronts are generators of large dust storms. A classic example of an intense cold front and dust storm occurred during the week of 20 February 1977. The accompanying dust storm was one of the most extensive ever known to occur in the United States. As strong post-frontal winds whipped across the Great Plains, dust was spread eastward into the Atlantic Ocean and southeastward into the Gulf of Mexico. Aircraft pilots reported dust churned up to heights of 9 km.

c. Cyclones with steep pressure gradients

The development of strong wave cyclones is covered

throughly in most general meteorology texts. It is, however, imperative to mention a steep pressure gradient cyclone that occurs commonly in central to south central United States during spring months. This synoptic-scale system is referred to as a leeside trough or lee wave and is often associated with surface winds as high as 20 to 30 m $s^{-1}$ and blowing dust in the Great Plains. A leeside trough can be expected to deepen and persist as long as air flow remains strong and perpendicular to a mountain range.

Leeside trough development and its effects are discussed in many texts and articles. Scorer (1949, 1954) did extensive theoretcial work on the problem of lee waves. Haltiner and Martin (1957) discussed the development of leeside troughs associated with conservation of potential vorticity. Scoggins and Incrocci (1973) studied relationships between turbulence and mountain waves.

d. Thunderstorms and whirlwinds

Thunderstorm-generated blowing dust occurs more frequently than synoptic-scale dust storms but is more localized. The strong downdraft of a thunderstorm creates a gust front with strong winds and resulting blowing dust in arid and semiarid regions. In the United States, this type of dust storm is a frequent occurrence in Arizona and other southwestern states during July and August.

Whirlwinds are even smaller in scale than thunderstorms,

and the associated blowing dust is of short duration. In the United States they present little or no problem to ground and air operations. These whirlwinds are known as dust devils and they occur over dry and dusty areas. Typically, they are the result of strong convection during sunny, hot, calm afternoons. This type generally is several meters in diameter at the base and normally 30 to 90 m in height.

e. Satellite imagery

The launch of the Tiros 1 experimental satellite on 1 April 1960 marked the beginning of an important new branch of meteorology--satellite meteorology. In the ensuing years, the satellite meteorology program progressed rapidly. Satellite imagery is used operationally and provides a large amount of useful data, especially for data-sparse areas of the earth such as the oceans. Even though resolution of satellite imagery has improved greatly over the years, it is important to note that satellite data become most reliable when used in conjunction with conventional data.

Earth-synchronous satellites maintain constant positions above earth and provide detailed blown-up views of special problem areas. The first dust clouds to be identified by satellite were over Africa; they were seen to move out over the Mediterranean Sea and Atlantic Ocean. Large dust clouds were spotted over the American Southwest during

the week of 20 February 1977. They were tracked hour-by-hour as they spread eastward over the Atlantic and south-eastward over the Gulf of Mexico (Fig. 13). Dust clouds with this storm were observed to originate in northeast Colorado and west of Lubbock, Texas (Fig. 14). This corresponds well with the wind-deposited sand and silt depicted in Fig. 9 (p. 19).

Dust storms appear on satellite images as dull flat areas of uniform texture that trail out into flimsy wisps downstream. In visible pictures they are medium gray in color, lighter than the ground but not as bright as clouds in well-illuminated areas. Terrain features can be seen through thin dust clouds. In infrared images, the dust clouds appear medium gray in color. This indicates that upper surfaces of dust clouds are colder than the ground but warmer than most clouds.

A disadvantage of satellite imagery is that not all weather stations have direct read-out capabilities and thus do not have access to the high resolution images. The satellite images sent via weather facimile circuits generally do not provide sufficient resolution to distinguish dust clouds.

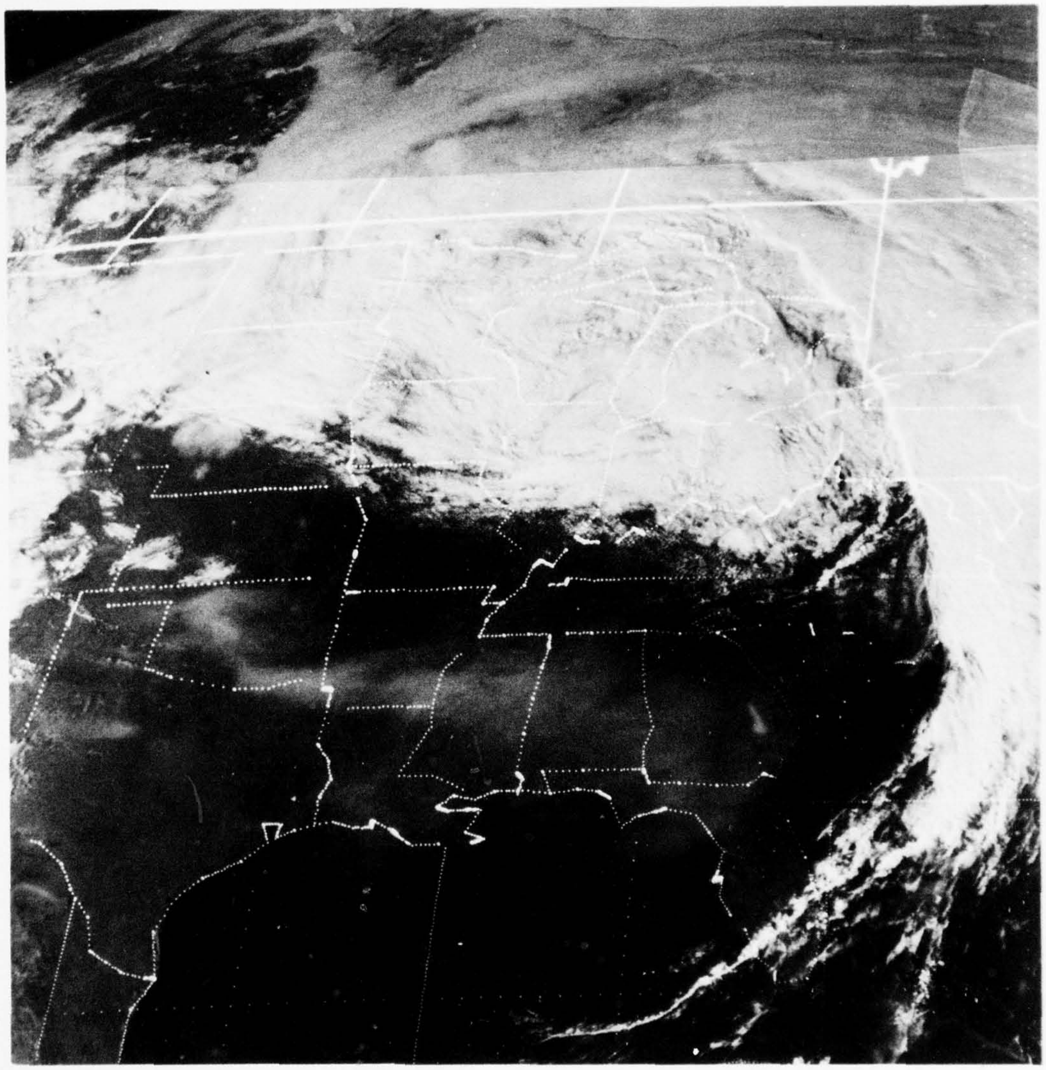

Fig. 13. GOES-1 visible 2-km resolution satellite photograph taken at 2030 GMT 24 February 1977.

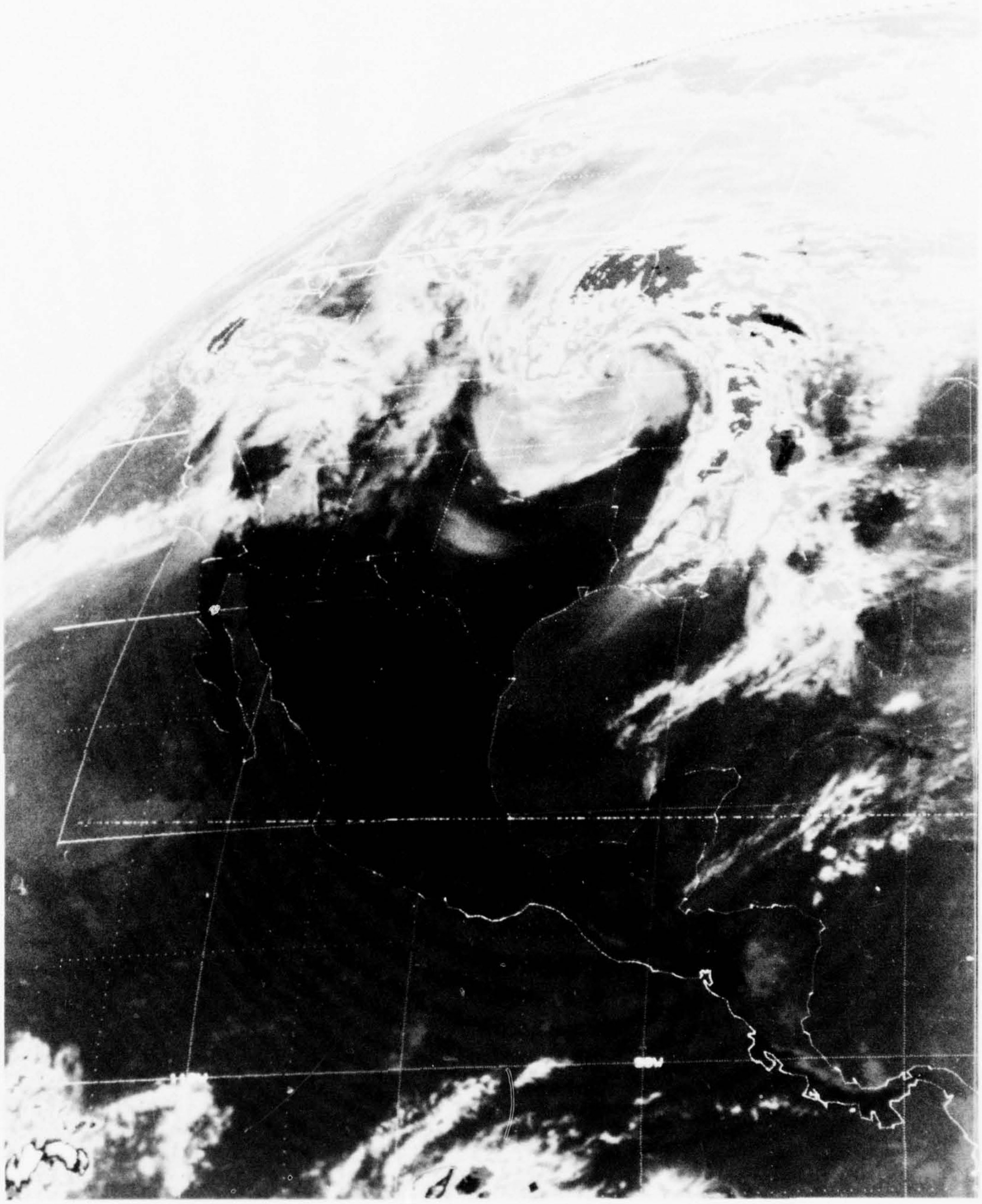

Fig. 14. GOES-1 enhanced infrared (IR) 8-km resolution satellite photograph taken at 1845 GMT 23 February 1977.

## 3. NON-METEOROLOGICAL CONDITIONS

### a. General

Forecasters in the Southern Great Plains must use all available data in order to get the "big picture" and provide a more timely and useful product. Dust storms are a difficult meteorological phenomenon to predict. Their infrequent occurrence can lull a forecaster into neglecting this weather feature.

Non-meteorological conditions include knowledge of surface properties, current soil conservation practices, and particle erosion and transport mechanisms.

### b. Knowledge of surface properties

Local geographical terrain features are significant for forecasting. Equally important when considering dust storms is a knowledge of the surface properties. The state of the surface has a profound effect upon erodibility of particles which cover that surface. Large roughness elements such as trees and shrubs provide leeside sheltering and generally are quite effective in combating wind erosion. Smaller roughness elements such as clods or aggregrates of soil, rocks, and small obstacles provide leeside protection for a small area. Plant cover and residue also provide some protection from wind erosion.

### c. Current soil conservation practices

Early records show that dust storms occurred before

cultivation of the soil began. The following extract is from official Dodge City, Kansas, weather records. "April 6, 1893: The dust was blinding and was deposited so thickly on office furniture that everything looked as though it were covered by a layer of dirt prepared for a hotbed" (Marlin, 1946). Man's cultivation, however, has added greatly to the problem of blowing dust. Chepil (1957) pointed out that early settlers in the Great Plains failed to perceive that removal or destruction of vegetation cover from the land surface is the basic cause of dust storms. Vegetation cover was destroyed by burning, overgrazing, plowing grasslands, and turning under vegetation residues. A high correlation exists between greatest frequency of blowing dust and loose soil from plowing and planting during spring. Conservation has become a familiar and necessary requirement of the farmers in the Great Plains.

Forecasters in the Southern Great Plains should become familiar with the soil conservation practices being adhered to in their local area and, more importantly, those used upstream of their area since dust is advected by strong winds. These conservation practices are described in many texts. The county agriculture agent will know how these conservation methods are being used in the local area. The forecasters must keep current on these conditions because they change throughout the year. Soil conservation practices may include crop rotation, contour plowing to form clods,

shelter-belts and wind breaks, stripcropping, and leaving harvest residue on soil surfaces. Other civilian and military operations that disturb soil conditions should be considered also.

d. Particle erosion and transport mechanisms

Hilst and Nickola (1959) suggest that particles generally at rest on the surface may be moved by two processes. As air moves past a particle, it may exert a viscous drag sufficient to accelerate the particle, which may become airborne. When airborne particles impinge upon the surface, they may bounce back into an air stream, shatter as a result of collision, slide along the surface, dislodge other particles, become absorbed in the surface with no further particle movement, or they may chip off pieces of surface elements which in turn become airborne.

After a particle has been dislodged from its resting place, it may be transported in any of three ways (Fig. 15):

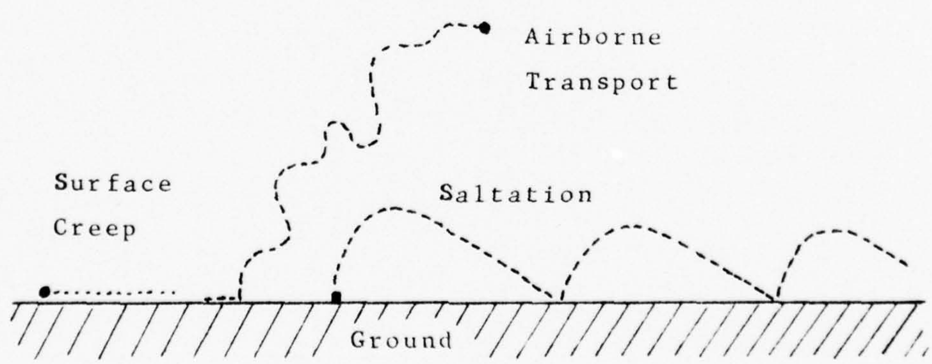


Fig. 15. Mechanisms of particle transport (after Hilst and Nickola, 1959).

1) surface creep--sliding or rolling along the surface; 2) suspension--airborne particle transport; and 3) saltation--leaps and bounds. The mode of transport of soil particles generally is surface creep until wind speeds become sufficiently strong for saltation and airborne transport.

## 4. SOURCES AND ACCURACY OF THE DATA

### a. Sources

Data for this study were obtained from the U.S. Air Force Environmental Technical Applications Center, Scott Air Force Base, Illinois. It consisted of 754,242 hourly and special surface observations from 34 Southern Great Plains weather reporting stations (Appendix A). The time period considered was February through May for the years 1966-1975. Observations of dust with visibility below 11,200 m (7 mi) were extracted for use in this study. These observations, which totaled 5056, were then used for analysis of such parameters as wind speed, visibility, and time of occurrence.

Daily precipitation totals for the same time period were obtained from the National Climatic Center, Asheville, North Carolina. These data were used to plot an Antecedent Precipitation Index (McQuigg, 1954) to determine soil dryness and drought conditions (Appendix B). The amount of precipitation was correlated with parameters such as the number of days since the last measureable precipitation prior to dust occurrence.

### b. Accuracy

Surface data provide the only hourly measurements which can be analyzed. Accuracy of data must be considered before any analysis can be attempted. Errors in observations can affect accuracy significantly. Observational errors which

occur pertain to human errors, improper recording, or inaccurate transmission of data.

Visibility and wind observations are two areas open to human error. Visibility is generally a subjective measurement dependent on how an observer interprets the prevailing visibility. It tends to become a bias measurement as observers favor certain increments of reportable distances. Wind direction and speed measurements are averaged over a period of time which tends to filter certain frequencies.

A further restriction to accuracy is the limitation and location of weather instruments. Although they are designed to be simple, durable, and inexpensive, errors do occur. One of the major factors in instrument design is the capability to respond to weather parameters such as rapid temperature or pressure changes. Most equipment responds logarithmically with a rapid change. Location of instruments can greatly affect representative measurements. Local terrain, vegetation, buildings, etc. interfere with accurate measurements. For example, standardization of height placement of wind measurement equipment has not been realized. In many instances installations are on the roofs of buildings. These instruments always record too high a wind speed because of crowding of the streamlines as the air flows over the building. Another example is measurement of precipitation. Rain gauges catch only a small

sample of the depth of water over a large area. This has a significant impact on representative measurements of precipitation. Additionally, since the wind speed normally increases logarithmically with height, there is a loss of amount of precipitation collected when the rain gauge is located at greater heights. Rain gauges also affect air flow around them in producing upward currents on their windward side and downward currents to leeward.

Data used for this study included surface observations from civilian and military installations that may differ on such things as equipment type and placement. Bias was evident in many of the measurements. For instance, it was noted that visibility mostly was reported in certain increments such as 1600 m, 3200 m, 4800 m, etc. Certain wind speeds seemed to be favored also, such as 5.1 and 10.2 $m\,s^{-1}$.

Other problems such as the lack of sufficient number of weather reporting facilities may not allow adequate analysis of small-scale, but significant, weather phenomena. It should be noted, however, that the 6-hr and/or 3-hr synoptic surface observations are the most accurate and frequent data available for synoptic analysis and have proved invaluable in many instances.

## 5. PRESENTATION OF RESULTS

### a. General

Some of the results were favorable whereas others failed to represent expected relations. Griffiths (1966) pointed out that one must be careful when using statistics and not accept blindly a cycle that is inferred from the arithmetic. Interpretation of data was difficult because of the sporadic nature of the pertinent weather in the semiarid-to-arid southern plains. For instance, spring convective showers generally occurred with synoptic weather phenomena such as cold fronts and squall lines. These showers were often locally heavy and gave large precipitation measurements. Averaging these measurements over an area smooths the analysis and tends to give misleading results. The complexity of dust storm generation required careful consideration of statistical results.

Total dust observations for February through May 1966-1975 totaled 5056 for 34 stations in the Southern Great Plains. This represented 0.67 percent of the total 754,242 surface observations reported during this period. Comparing this with Fig. 11 (p. 23) shows that this percentage is close to values along the perimeter of the Southern Great Plains; however, values in north central and northwest Texas are higher due to the dry climate and heavy deposits of silt and sand in the boardering regions of Texas and New Mexico.

Because of the change of precipitation with longitude, viz., precipitation amounts increase eastward in the Southern Great Plains, the region of study was separated into four smaller regions each of 150-km radius to obtain more detailed and homogeneous results. Two regions are located in the drier western half and the other two in the wetter eastern half of the general area of study (Fig. 16).

b. Time of occurrence

The Southern Great Plains experiences a spring maximum of occurrence of dust. The loss of vegetation cover as a result of drought or disturbance of vegetation cover by agricultural activity in the spring adds significantly to the blowing dust problem. During winter months, synoptic weather conditions favoring strong winds such as thunderstorms and leeside troughs generally occur less frequently. In addition, the ground in winter may become frozen, thereby increasing the cohesive nature of the soil particles, and this would inhibit much of the soil erosion.

The number of reported dust occurrences varies from year-to-year. For this study the maximum reported observations of dust was 1426 during the spring of 1974 and a minimum of 103 during 1972 (Fig. 17). Several reasons could explain the high value for 1974. The spring of 1974 was very dry in regions 1 and 2 and sporadic moisture fell in regions 3 and 4 (Fig. 18). Former director of the National Center for Atmospheric Research, Walter Orr Roberts,

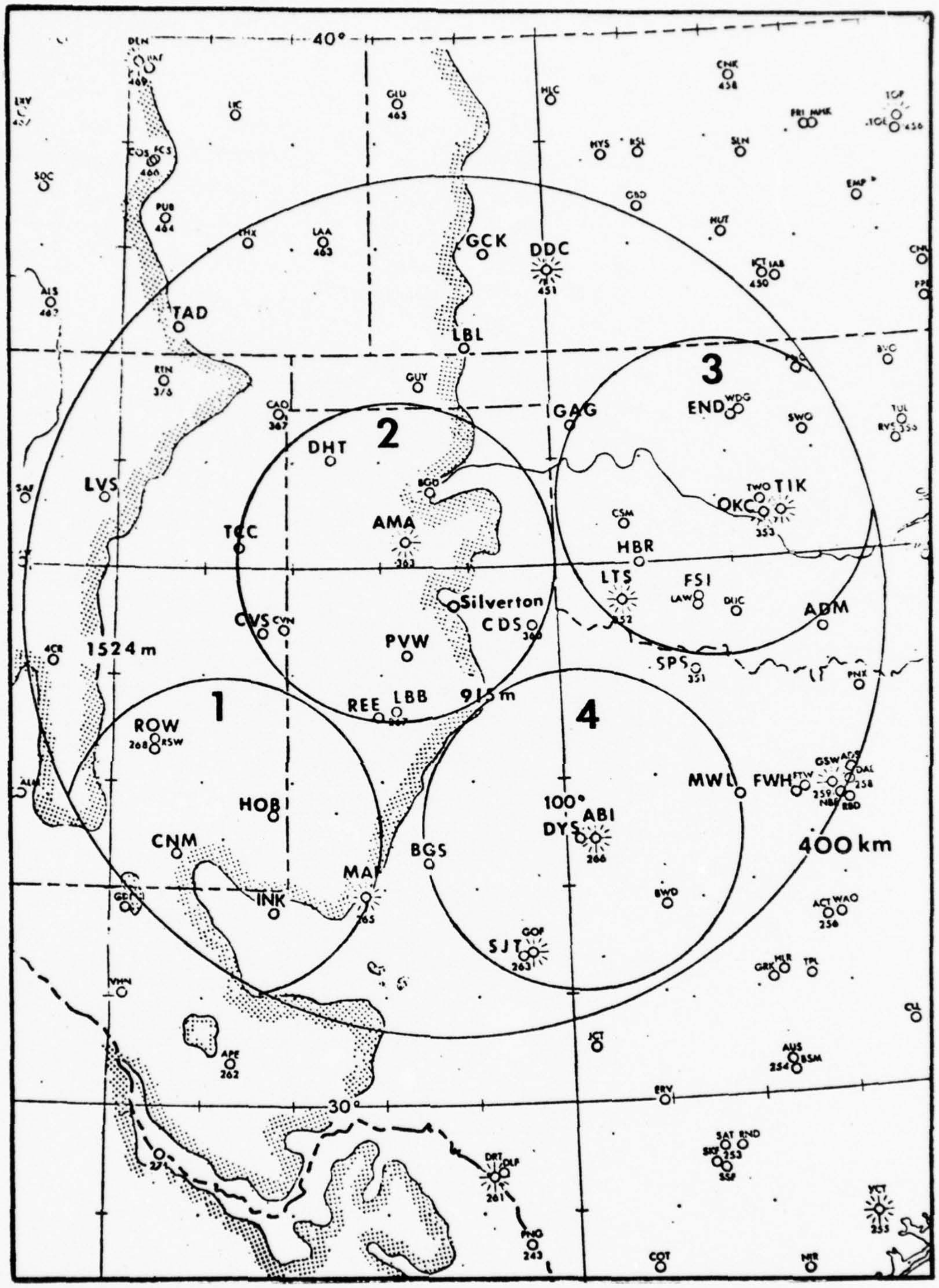


Fig. 16. General area of study divided into four regions. Each region is depicted by a circle with radius of 150 km.

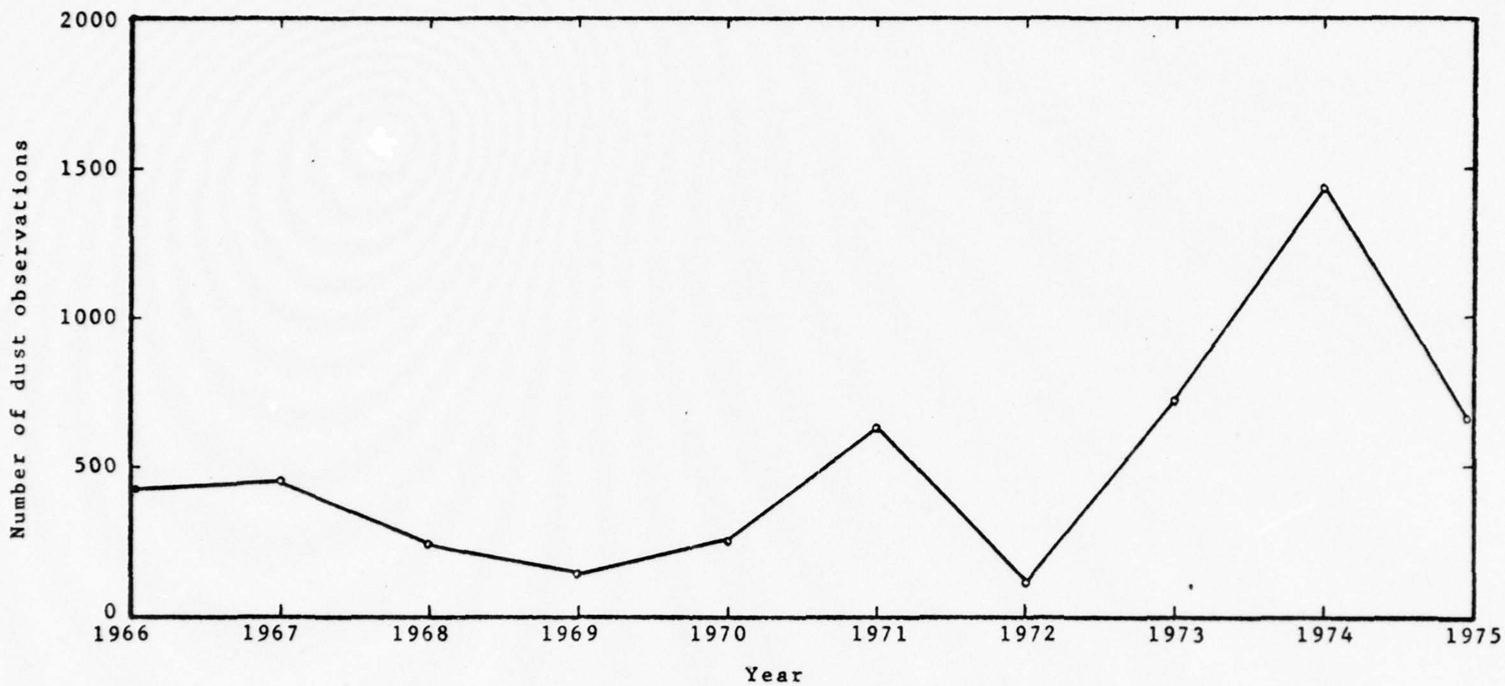


Fig. 17. Yearly distribution of 5056 dust observations from 34 Southern Great Plain weather stations for February-May 1966-1975.

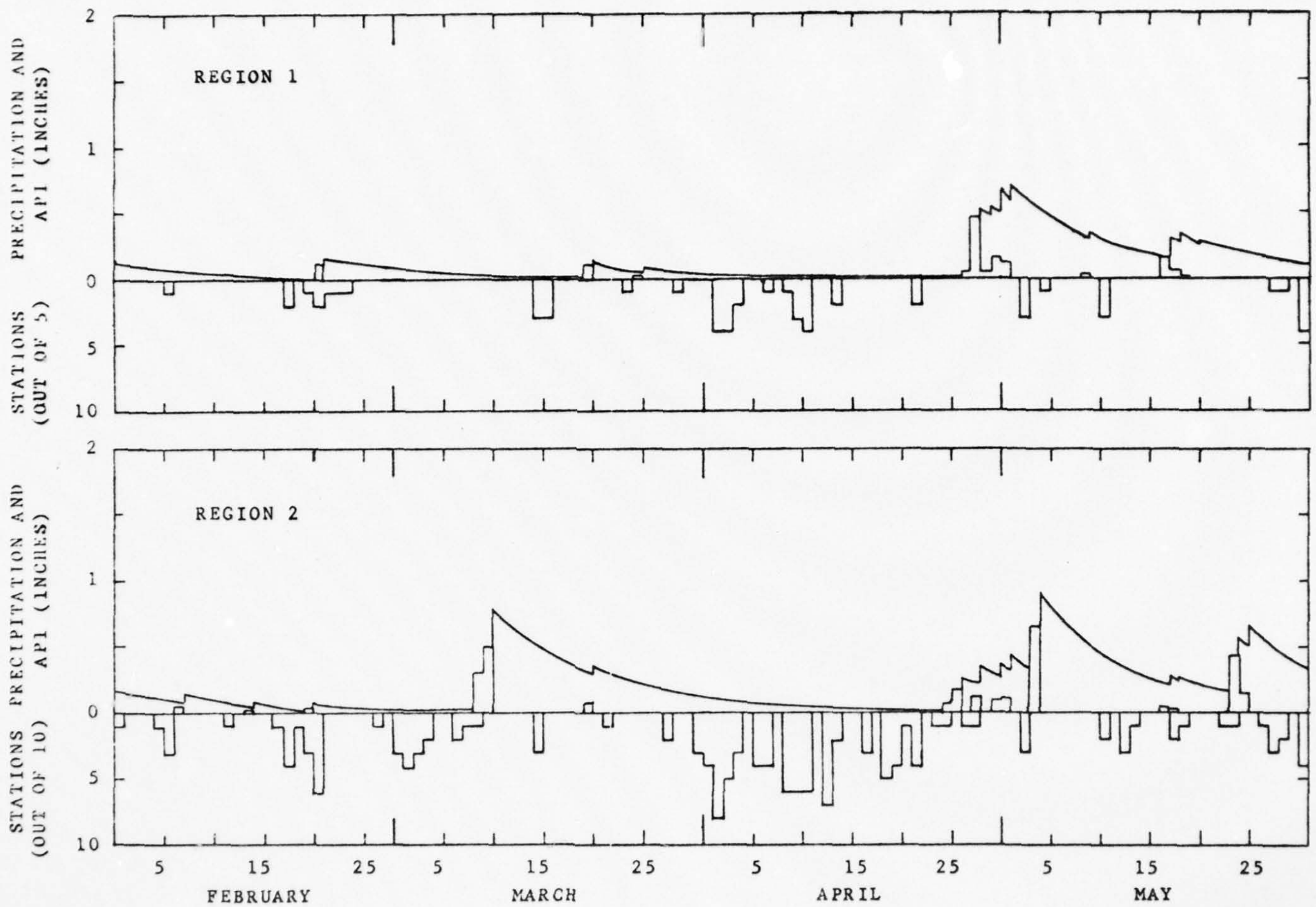


Fig. 18. Comparison of daily mean precipitation amounts and Antecedent Precipitation Index (API) profiles with number of stations reporting dust for February-May 1974 in four regions of the Southern Great Plains.

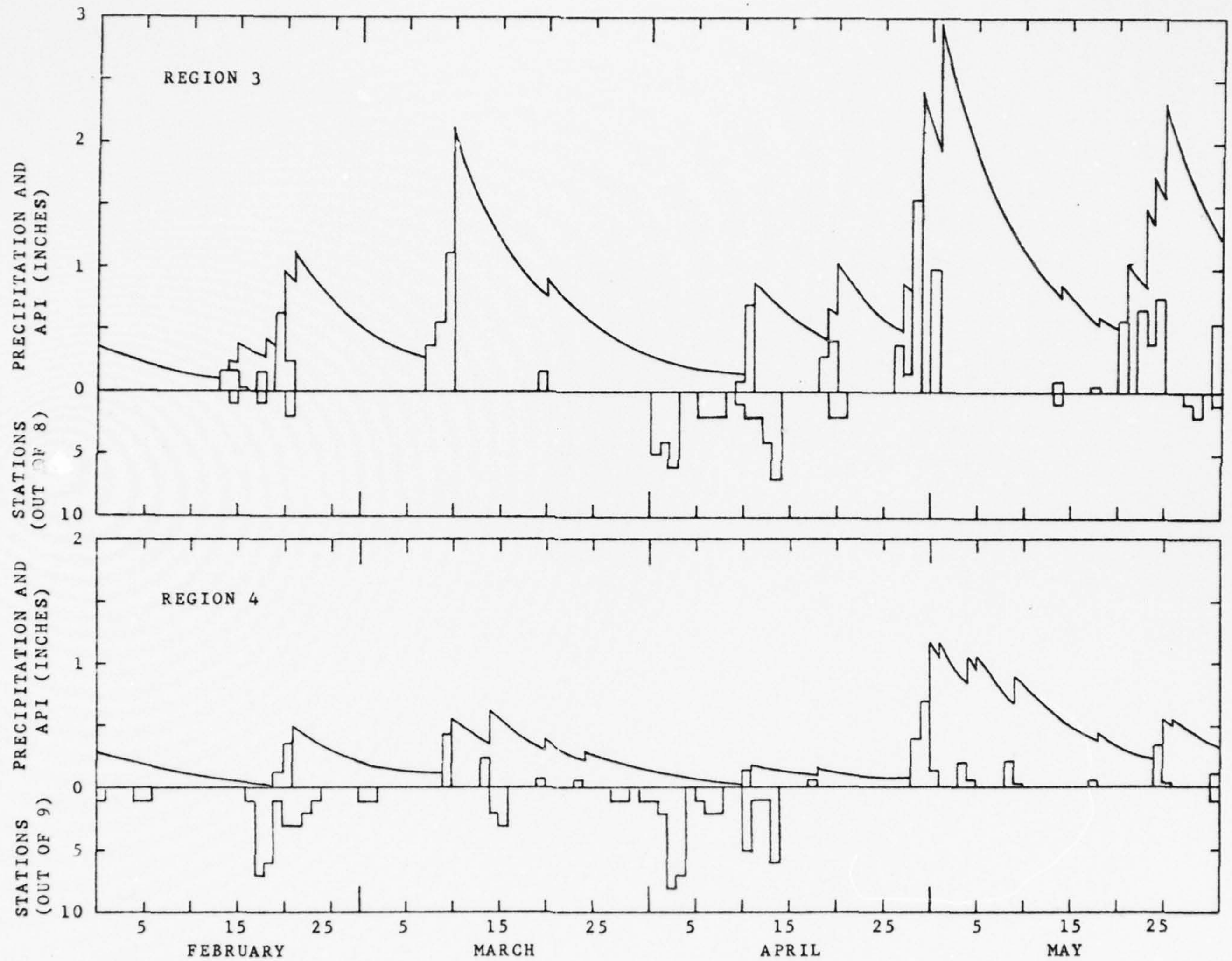


Fig. 18. (continued)

pointed out that a major rainstorm kept 1974 from being labeled a drought year in the Great Plains (Kornberg, 1977). Richard Weaver, a soil scientist at Texas A&M University, indicated that drought conditions in 1974 would significantly reduce vegetation cover and provide favorable conditions for soil erosion. Also the dry year of 1974 was preceded by several years of low precipitation rates during spring months. This tends to support the comment by Fryrear and Randel (1972) that if rainfall is below normal for 2 years, little or no crop residue is produced and erosion may be expected the following year.

The total dust observations for the entire period of study were compared with time of day and month of year to determine the period of maximum frequency. Fig. 19 shows that the greatest number of observations occurred in April with a maximum at 2200 GMT. The greatest number of observations occur during the afternoon hours when turbulent mixing from thermal instability is greatest and the atmospheric boundary layer is deep. This results in the dust being spread or advected farther horizontally and vertically than during stable atmospheric conditions.

c. Precipitation as a forecast parameter

Sporadic convective showers typify the weather in the Southern Great Plains during spring months. Rainfall often occurs as violent bursts of major rainstorms which may bring such a region an appreciable portion of its annual rainfall.

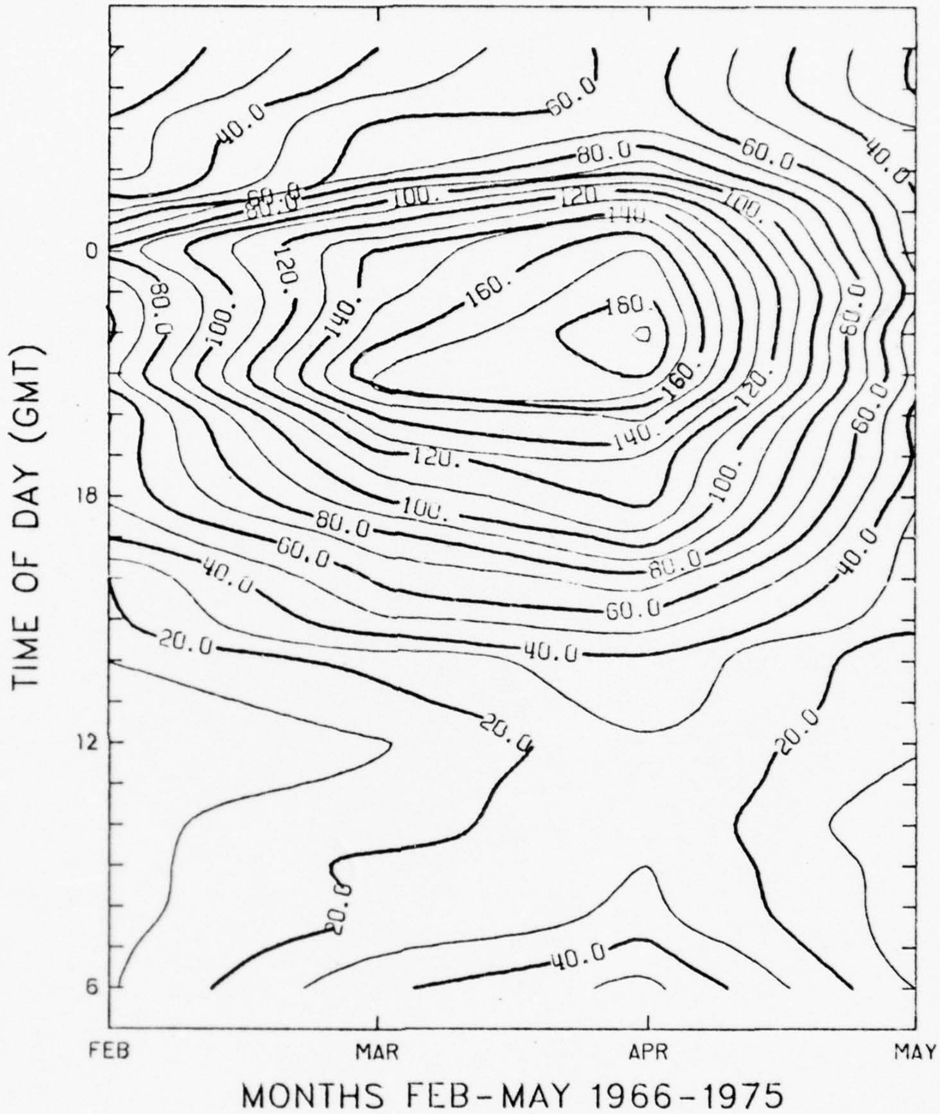


Fig. 19. Contoured frequency graph depicting the comparison of monthly dust observations with time of day of occurrence. Contours are labeled in number of observations and the data base includes 5056 dust reports from 34 Southern Great Plains stations during February-May 1966-1975.

In addition, evaporation and runoff during heavy downbursts from shower activity are very high. This prevents much of the moisture from soaking into the soil and percolating downward, and thus allows the topsoil to dry quickly. Hence, a needed criterion for blowing dust is produced--dry loose soil.

In spite of the problems encountered and difficulty involved when analyzing precipitation statistics, several relevant ersults were revealed during analyses. An Antecedent Precipitation Index (API) was calculated from mean daily precipitation for the four separate regions to overcome part of the problem associated with the sporadic nature of rainfall in the southern plains. The API was used as an indicator of soil dryness. An average daily amount of precipitation for each region was obtained by using the daily total amounts from stations within each region. The correlation of the API decreasing with a larger number of stations reporting dust was generally in good agreement, viz., as the soil becomes drier more stations report dust (Fig. 18, p. 43).

The amount of precipitation prior to an area dust storm and the API were analyzed with the number of days without precipitation preceding the storm. An area dust storm was defined as a case when two or more of the 34 stations reported dust. It was anticipated that increasing amounts of moisture should increase the number of dry days before a

dust storm. Results revealed that the API had a more significant correlation than precipitation totals before a storm (Table 2). The correlation coefficient (r) for the

TABLE 2. Correlation of Antecedent Precipitation Index (API) and precipitation amounts with number of days without precipitation prior to a dust storm (API was the value on the day of dust occurrence).

| Area | Parameter | Correlation coefficient (r) | Significance probability |
|---|---|---|---|
| Southern | API | -0.400 | 0.0001 |
| Great Plains | Amount | -0.164 | 0.0005 |
| Region 1 | API | -0.472 | 0.0001 |
| | Amount | -0.139 | 0.1519 |
| Region 2 | API | -0.431 | 0.0001 |
| | Amount | -0.070 | 0.4575 |
| Region 3 | API | -0.372 | 0.0001 |
| | Amount | -0.143 | 0.1241 |
| Region 4 | API | -0.393 | 0.0001 |
| | Amount | -0.129 | 0.1712 |

API for the southern plains was -0.40 whereas for precipitation amount it was -0.16. Correlations were analyzed with the Texas A&M University IBM 360 computer by using the Statistical Analysis System (SAS) programs. The Spearman rank correlation coefficient is given by

$$r = 1 - \frac{6\Sigma D^2}{N(N^2-1)}$$

where D equals the difference between ranks of corresponding values of random variables X and Y, and N equals the number of pairs of values (X,Y) in the data. The correlation varies

between -1 for perfect disagreement and +1 for perfect agreement. To determine the significance of the resultant correlation coefficient, the null hypothesis, $H_o: \rho \neq 0$, was made. This implies that $\rho$, the total population correlation coefficient, was significantly different from 0. Whether the hypothesis is rejected or accepted is called a test of the hypothesis. The level of significance is the maximum probability with which an hypothesis is rejected when it should have been accepted. In meteorology a level of significance of 0.05 or 5 percent is frequently used. The significance probability of 0.0001 for the API parameter in Table 2 indicates that given the entire population, the probability of getting a correlation coefficient greater than or equal to the one presented is 1 in 10,000. This means that correlation coefficients are significant when significance probabilities are less than or equal to 0.05.

Several results in Table 2 need to be noted. First, notice that the western regions 1 and 2 with their drier climate gave higher correlations. Next, the correlation coefficient for the amount of precipitation before a dust occurrence and the number of dry days preceeding dust for the southern plains presents a questionable result. Following a wet spell or heavy rain, one might be led to think that the number of dry days before a dust occurrence would increase; however, the results indicated a negative correlation. This was due most likely to the fact that spring

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precipitation in this area was generally associated with convective activity of squall lines, fronts, and air mass thunderstorms. These phenomena produced strong winds which generated blowing dust. Another consideration was that blowing dust may have been advected into an area where precipitation was occurring. Consequently, precipitation amounts before a dust storm do not appear to be a relative parameter when considering dust occurrence.

A significant correlation between visibility and API or visibility and precipitation amount could not be found; however, a negative correlation exists between the minimum observed visibility during dust storms and the number of stations reporting dust. The correlation coefficient and significance probability were -0.288 and 0.0001 respectively for 175 dust storms when five or more stations reported dust. This indicated that when a storm intensified or visibility decreased, the number of stations reporting dust increased.

The statistical analysis favors API as an indicator of soil dryness which was a significant ingredient for blowing dust. The frequencies of occurrence for API and precipitation amounts for 483 area dust storms are presented in Table 3. Note that the lowest values of API on the day of a dust storm occurred in regions 1 and 2. The semi-arid-to-arid climate in these regions account for the lower values.

TABLE 3. Frequencies of Antecedent Precipitation Index (API) on the day of a dust storm and the amount of precipitation before a dust storm.

| Area | Frequency (%) | API value ≤ (in.) | Amount of precipitation ≤ (in.) |
|---|---|---|---|
| Southern Great Plains | 50 | 0.25 | 0.13 |
| | 75 | 0.49 | 0.38 |
| | 90 | 0.87 | 0.85 |
| Region 1 | 50 | 0.08 | 0.05 |
| | 75 | 0.19 | 0.13 |
| | 90 | 0.32 | 0.34 |
| Region 2 | 50 | 0.18 | 0.09 |
| | 75 | 0.43 | 0.38 |
| | 90 | 0.67 | 0.81 |
| Region 3 | 50 | 0.41 | 0.23 |
| | 75 | 0.74 | 0.59 |
| | 90 | 1.18 | 1.04 |
| Region 4 | 50 | 0.30 | 0.20 |
| | 75 | 0.62 | 0.50 |
| | 90 | 1.16 | 1.18 |

### d. Wind as a forecast parameter

During unstable conditions with turbulent mixing of the atmospheric boundary layer, surface wind gusts were a common occurrence. Wind gusts may provide the necessary force to dislodge a soil particle, but the particle will remain airborne only if turbulent winds or vertical currents are sufficient to keep it suspended. As wind speed increases, so does the amount of soil erosion and the size of the particles dislodged and moved. Wind direction is important when considering the location of soil deposits

most susceptible to wind erosion. Therefore, wind gust, speed, and direction are significantly related to dust storm generation.

Correlations were made between visibility and the following wind parameters: wind speed, wind gusts, wind speed squared, wind gust squared, natural logarithm of wind speed, and natural logarithm of wind gusts. The intent of this portion of the analyses was to demonstrate that a correlation exists between reduced visibilities and some function of increasing wind speeds. Table 4 shows that correlation coefficients were significant in some instances; nevertheless, correlations were not as significant as anticipated. The wind speed parameter gave better correlations with visibility than wind gusts. This indicated that wind speed was a better forecast parameter of dust storm intensity or of decreasing visibility due to dust. Wind gusts, however, were important when considering generation of blowing dust. Oftentimes the lowest visibility experienced during a dust storm occurred with the initial gust from a thunderstorm or following a frontal passage. Note in Table 4 that squaring and taking natural logarithms of the wind speed and gusts did not significantly improve the correlations. Dropping upper and lower limits of wind speed and gusts also failed to increase the correlation coefficients. In fact, some correlations were reduced. Region 1 had the weakest wind speed correlation. Most likely this was due to the frequent

TABLE 4. Correlations of visibility with wind parameters.

| Area | Wind parameter | Correlation coefficient (r) | Significance probability | Number of observations |
|---|---|---|---|---|
| Southern Great Plains | Wind speed | -0.284 | 0.0001 | 5033 |
| Region 1 | | -0.152 | 0.0001 | 635 |
| 2 | | -0.291 | 0.0001 | 2067 |
| 3 | | -0.274 | 0.0001 | 951 |
| 4 | | -0.325 | 0.0001 | 1380 |
| Southern Great Plains | Wind speed squared | -0.283 | 0.0001 | 5033 |
| Region 1 | | -0.116 | 0.0033 | 635 |
| 2 | | -0.298 | 0.0001 | 2067 |
| 3 | | -0.272 | 0.0001 | 951 |
| 4 | | -0.313 | 0.0001 | 1380 |
| Southern Great Plains | Wind gust | -0.175 | 0.0001 | 2517 |
| Region 1 | | 0.003 | 0.9670 | 224 |
| 2 | | -0.177 | 0.0001 | 1133 |
| 3 | | -0.276 | 0.0001 | 610 |
| 4 | | -0.107 | 0.0119 | 550 |
| Southern Great Plains | Wind gust squared | -0.171 | 0.0001 | 2517 |
| Region 1 | | 0.038 | 0.5670 | 224 |
| 2 | | -0.177 | 0.0001 | 1133 |
| 3 | | -0.271 | 0.0001 | 610 |
| 4 | | -0.110 | 0.0098 | 550 |
| Southern Great Plains | Natural log of | -0.257 | 0.0001 | 5002 |
| Region 1 | wind speed | -0.154 | 0.0001 | 613 |
| 2 | | -0.251 | 0.0001 | 2064 |
| 3 | | -0.245 | 0.0001 | 951 |
| 4 | | -0.283 | 0.0001 | 1374 |
| Southern Great Plains | Natural log of | -0.172 | 0.0001 | 2517 |
| Region 1 | wind gust | -0.014 | 0.8365 | 224 |
| 2 | | -0.166 | 0.0001 | 1133 |
| 3 | | -0.258 | 0.0001 | 610 |
| 4 | | -0.088 | 0.0391 | 550 |

springtime leeside trough that generated troughs and cyclones with steep pressure gradients in the lower troposphere. The surface trough generally was situated over eastern New Mexico in which case the winds increased eastward. Hence, strong winds were not as frequent in southeastern New Mexico as they were farther east in western and north central Texas. The low correlation value for region 1 indicates that wind speed does not explain as much of the variance in region 1 as in the other regions, where $r^2$ is proportional to the explained variation.

Wind direction was another parameter related to dust storms. Frequencies of wind direction were compiled to analyze the favorable wind directions for occurrences of blowing dust. Results are presented in Fig. 20. For the Southern Great Plains 55 percent of the dust observations were associated with southwest through northwest winds, and the maximum occurred with winds directly out of the west. Variations show in the individual regions, e.g., 53 percent of the blowing dust in region 1 was associated with north to northeast winds and region 4 had 50 percent of its dust occurrence with west to northwest winds. The reader should not interpret these results to imply that all winds from the aforementioned directions were associated with blowing dust.

To analyze percentages of all winds associated with dust, the maximum frequencies of wind speeds (Fig. 21) were

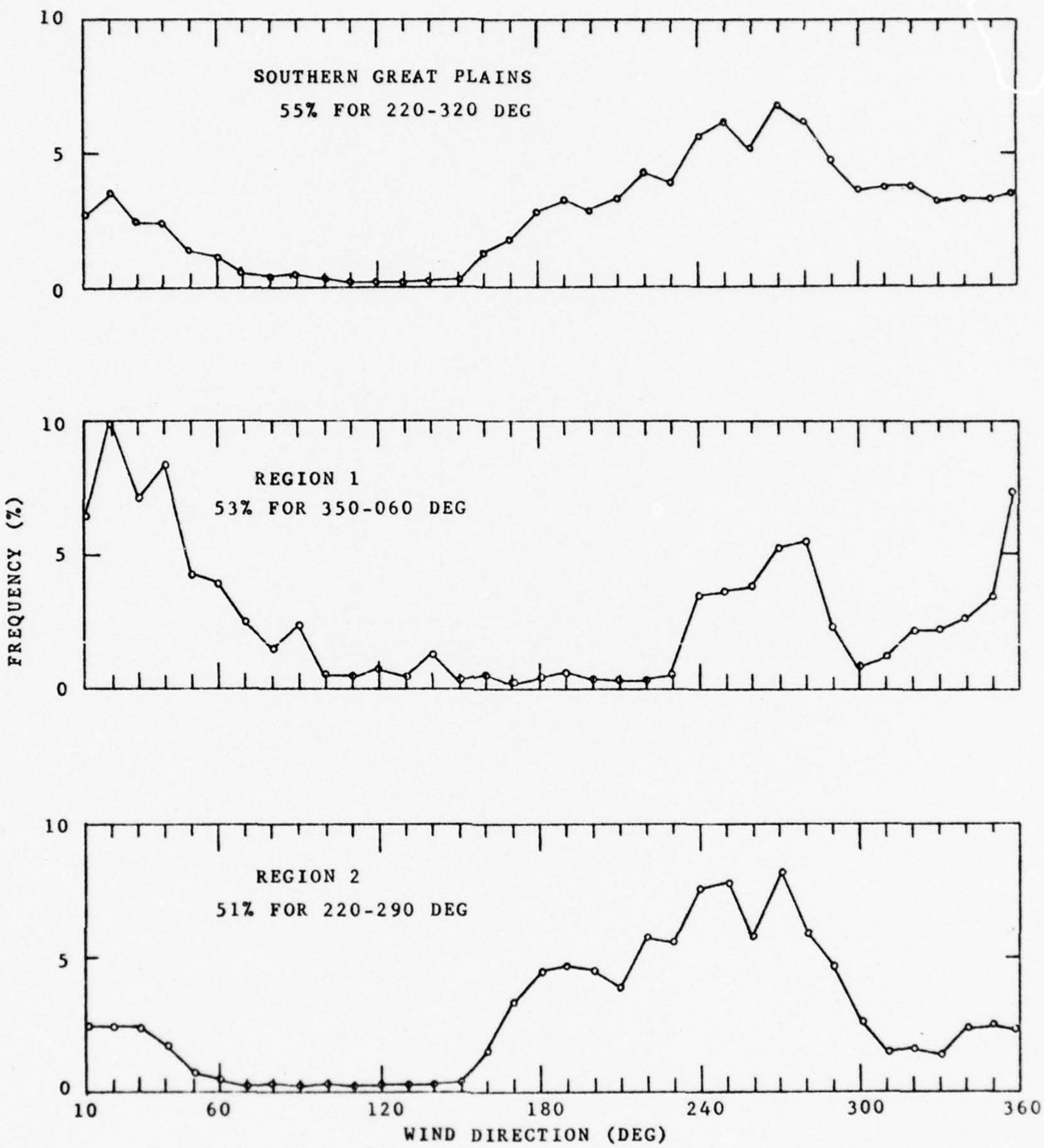


Fig. 20. Frequency distribution of wind directions associated with dust reports for the Southern Great Plains and four regions within the Southern Great Plains during February-May 1966-1975. The favored wind direction during dust occurrence is also indicated.

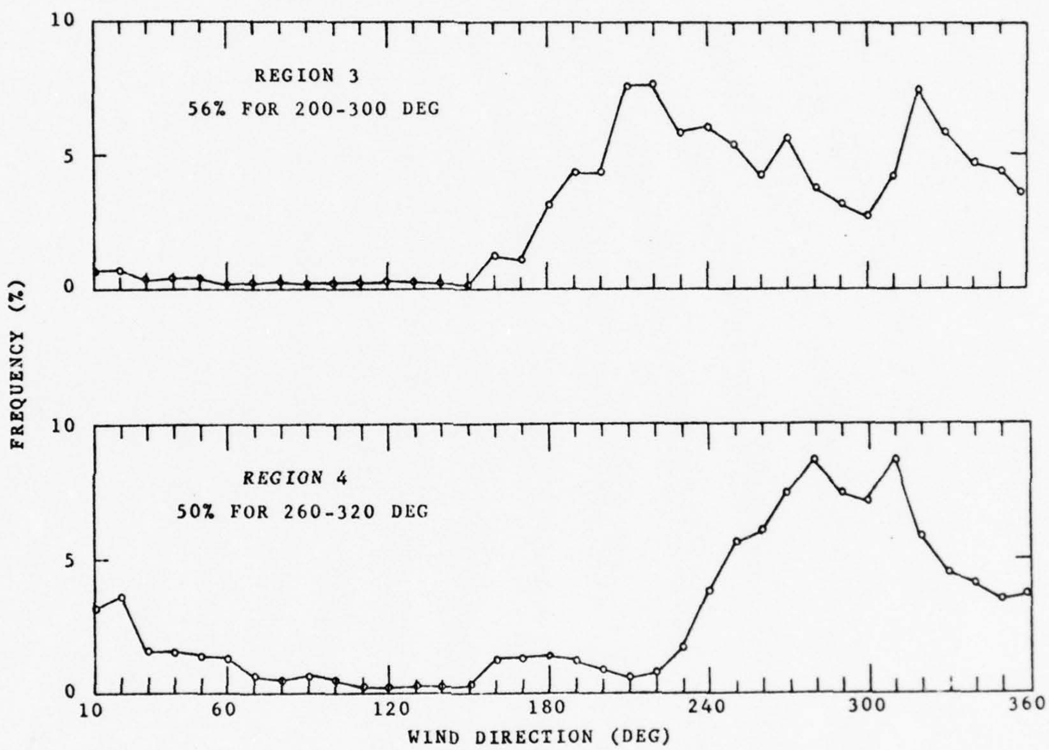


Fig. 20. (continued)

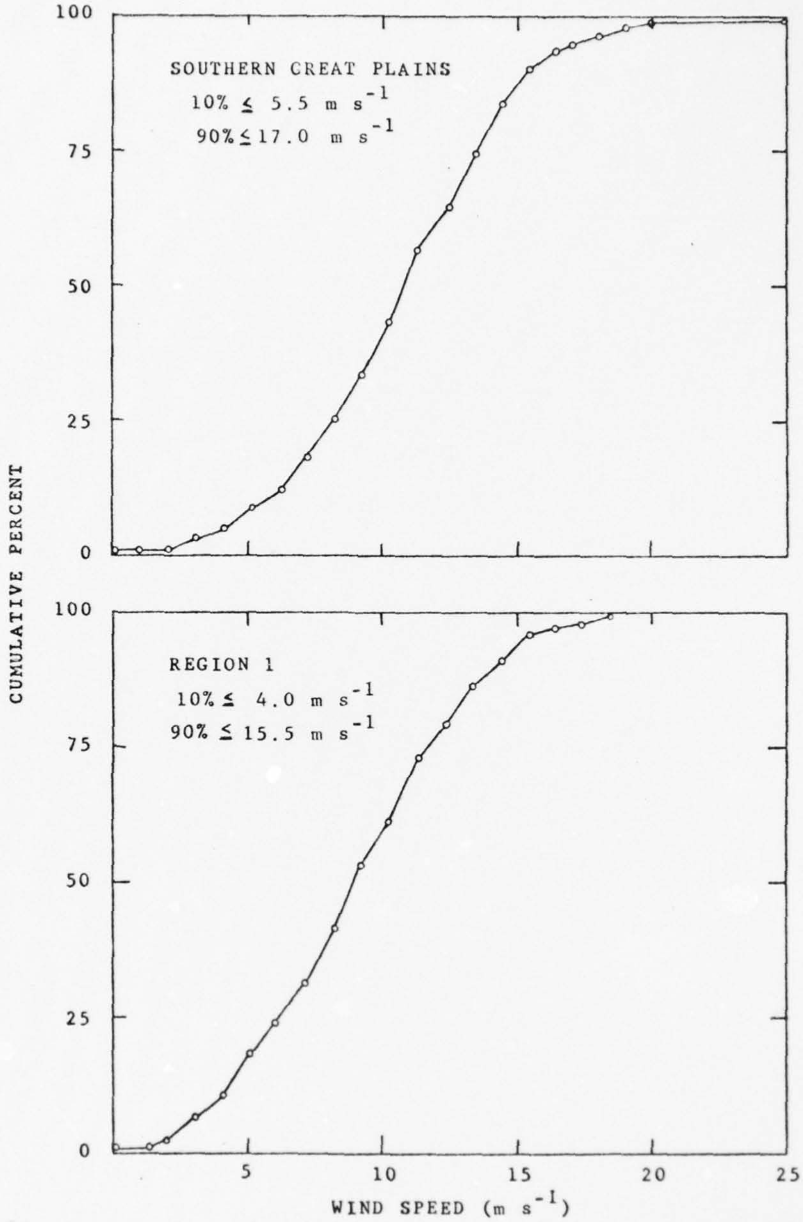


Fig. 21. Cumulative percent of wind speeds associated with dust reports for the Southern Great Plains and four regions within the Southern Great Plains during February-May 1966-1975. The lower and upper limits of 10% and 90% respectively are indicated.

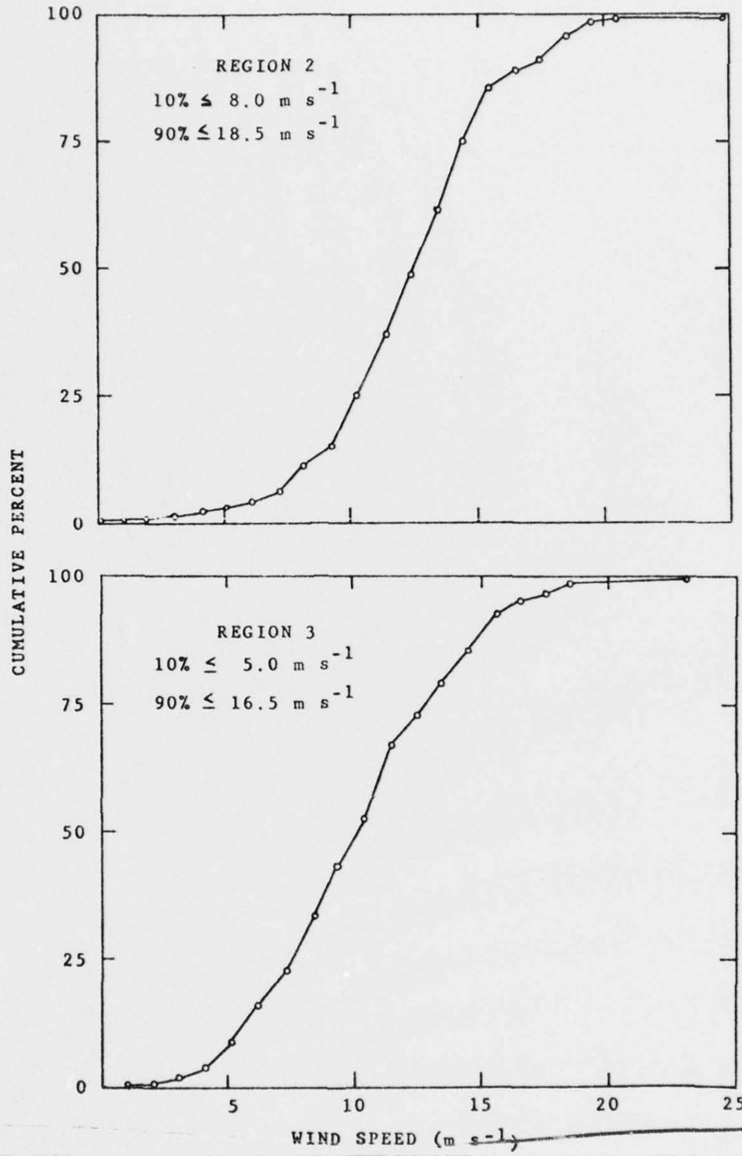


Fig. 21. (continued)

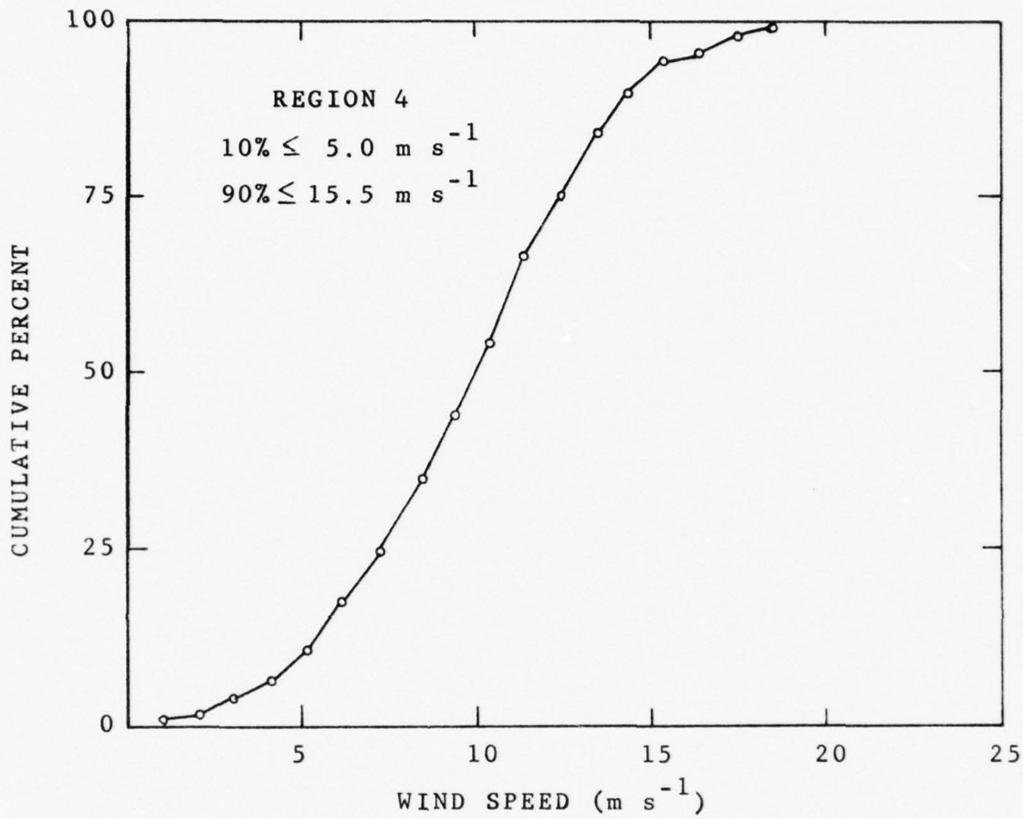


Fig. 21. (continued)

combined with favorable wind directions and related to the total number of winds from these directions. Results are presented in Table 5. For the Southern Great Plains the total number of observations associated with wind direction 220-320 deg was 174,601. This compares with 2772 associated with dust observations from this direction which only represents 1.6 percent of the total. Dust frequency increased greatly for wind speeds over 15 m $s^{-1}$. Data for a station in each region were compiled to compare actual total winds and winds laden with dust. Reese AFB, Texas, had the highest percentage of observations with dust. This corresponds with region 2 being the area of highest frequency of dust occurrence in the United States. It should be noted that the other stations sampled did not show a large percentage of winds with dust from favorable directions; therefore, one cannot conclude that the wind direction parameter alone would be a sufficient indicator of dust. Higher percentages were found for individual years. During the dry year of 1974, Reese AFB, Texas reported dust 63 percent of the time when wind directions were 260-300 deg, and Dyess AFB, Texas observed dust 25 percent of the time when wind directions were 260-320 deg.

e. Dew-point depression

Attempts were made to correlate temperature and dew-point depression with visibility. The temperature parameter failed to reveal any correlation and dew-point depression

TABLE 5. Comparison of the total observations of dust with the total observations for wind directions and speeds favorable for dust occurrence.

| Area | Wind direction (deg) | Wind speed (m $s^{-1}$) | Total observations | Total dust observations | % with dust |
|---|---|---|---|---|---|
| Southern Great Plains | 220-320 | All | 174,601 | 2,772 | 1.6 |
| | | <5 | 81,656 | 168 | 0.2 |
| | | 5-9 | 76,085 | 656 | 0.9 |
| | | 10-14 | 15,398 | 1,390 | 9.0 |
| | | 15-19 | 1,349 | 522 | 38.7 |
| | | ≥20 | 113 | 36 | 31.9 |
| Roswell, NM (Region 1) | 350-060 | 4-15.5 | 78 | 3 | 3.9 |
| Reese AFB, TX (Region 2) | 220-290 | 8-18.5 | 1,435 | 460 | 32.1 |
| Tinker AFB, OK (Region 3) | 220-300 | 5-16.5 | 571 | 25 | 4.4 |
| Dyess AFB, TX (Region 4) | 260-320 | 5-15.5 | 1,150 | 112 | 9.7 |

showed a weak negative correlation. As visibilities lowered, the depressions increased. The dew-point depression correlation coefficient for the Southern Great Plains was -0.057 for 4161 dust observations and the significance probability was 0.0002. Dew-point depressions were greater than 10°C for more than 90 percent of the observations associated with dust. Since dew-point depression is an indicator of humidity, it can be seen that small depressions or high humidities help curtail dust generation.

## 6. CONCLUSIONS AND RECOMMENDATIONS

### a. Conclusions

The objective of this investigation was to analyze dust storm generation in the Southern Great Plains and to determine significant relationships and relevance of parameters associated with dust. The study led to the following conclusions:

(1) The physical characteristics of the Southern Great Plains are favorable for dust storm generation.

(2) Source regions are imperative for dust occurrence at a particular location. Weather stations downwind and within proximity of a source region experience more dust than those stations located farther away. The dry sandy soils in eastern Colorado, western Oklahoma, and northwestern Texas provide sources for blowing dust.

(3) Soil conservation and agricultural practices greatly affect the probability of blowing dust. Dust occurrences increase when improper soil conservation methods are practiced, crop residue or plant cover are destroyed, and during periods of plowing and planting.

(4) Gusty strong winds are the primary weather phenomenon generating dust storms. These winds occur with frontal passages, squall lines, steep pressure

gradient cyclones or leeside troughs, and thunderstorms. The winds associated with cold fronts cause the most wide-spread area dust storms.

(5) The greatest frequency of dust occurs between 1800 to 0100 GMT (12:00 to 7:00 PM) during spring months.

(6) Because of the sporadic nature of springtime convective precipitation and smoothing due to area averaging, significant correlations between precipitation amounts and dust were not found.

(7) Dry years cause the loss of much plant cover and this results in increased potential for dust occurrences the following year.

(8) The Antecedent Precipitation Index (API) is a reasonable representation of soil dryness, which is significant when forecasting dust. As the API decreases, the number of stations reporting dust increases.

(9) Wind speed and direction are significantly correlated with dust occurrences. The percentage of winds associated with dust compared to all winds increases greatly for winds from direction 220-320 deg and speeds equal to or greater than 15 m $s^{-1}$. Favored wind direction for dust varies and is dependent on location with respect to source regions for dust generations. Blowing

dust is associated with a wind speed equal to or greater than 5 m $s^{-1}$.

(10) Dew-point depression is correlated weakly with visibility. As dew-point depression increases, visibility decreases or dust storm intensity increases. Occurrences of dust are generally associated with a dew-point depression equal to or greater than 10°C.

(11) The best possible forecast for dust can be made by combining parameters and conditions. Two types of occurrences of dust should be considered, namely, advected dust and dust generated in the local area. A summary of favorable parameters and conditions for these two types is outlined in Tables 6 and 7, which provide the forecaster a guide for forecasting occurrences of dust.

TABLE 6. Summary of favorable parameters and conditions for springtime advection of dust in the Southern Great Plains.

| Parameter or condition | Favorable when |
|---|---|
| Potential advection | Blowing dust generated upstream |
| Wind speed | $\geq$ 5 m $s^{-1}$ |
| Wind direction | Along the trajectory of the generated dust |
| Synoptic situation | Insures that the wind trajectory will continue to advect dust |

TABLE 7. Summary of favorable parameters and conditions for springtime generation of blowing dust in local areas of the Southern Great Plains.

| Parameter or condition | Favorable when |
|---|---|
| Location with respect to source region | Located downstream and within close proximity |
| Antecedent Precipitation Index (API) | $\leq$ 0.90 in. |
| Agricultural practices | Soil left unprotected |
| Previous dry years | Plant cover reduced |
| Wind speed | $\geq 15\ m\ s^{-1}$ |
| Wind direction | Southwest through northwest |
| Cold front | Passes through the area |
| Squall line | Passes through the area |
| Leeside trough | Deepening and increasing winds |
| Thunderstorm | Mature storm in local area or generates blowing dust upstream |
| Whirlwind | In local area |
| Time of day | 1800 to 0100 GMT |
| Surface dew-point depression | $\geq$ 10°C |

Items are listed in order of importance. After blowing dust has been generated upstream, wind speed becomes important in advection of dust; nevertheless, when wind speeds drop off as they often do at sundown, dust may still be advected by winds aloft even though surface winds may be weak or calm. Duration of a dust storm is a function of the height of the dust and wind speeds that advect the dust. Synoptic situations, such as a cold frontal passage, may change the wind direction and thus lessen the probability of advected dust. Forecasting dust generation is more difficult than determining advection of dust once it has been observed upstream. Some of the more important factors to take into account are the location with respect to a favorable source region, soil dryness as determined by an Antecedent Precipitation Index, agricultural practices, and wind speed and direction. Proper conservation methods will require that wind speeds be stronger to generate dust. The opposite holds true when heavy military or civilian operations in an area disturb the soil and destroy vegetation. Plant cover protects the soil from wind derosion by slowing and breaking the wind flow similar to the effects of a

snow fence. It should be noted that modification of parameters and conditions in Tables 6 and 7 will improve the effectiveness. Also, pilot reports can be useful in forecasting occurrences of dust.

b. Recommendations

Recommendations derived from this study include the following:

(1) Further study of dust storm characteristics is necessary for refinement of dust prediction for dust-prone southwestern United States and the Great Plains. Contingency tables need to be plotted to develop success rates for forecasting this phenomenon.

(2) Temperature related to stability may lead to a correlation with height and intensity of blowing dust. Vertical dust measurements with wind profiles also would prove useful in determining height and density of dust storms. At this point it is thought that the most improvement in forecasting will come from a study of the stability of the lower levels.

(3) Carlson and Cavery (1977) studied the radiative characteristics of Saharan dust. They concluded that depletion of solar energy by dust is largely due to absorption, and that backscatter to space

is not insignificant. They stated further that the vertical distribution of warming of the atmosphere by solar radiation is altered by dust and this could result in increased warming aloft and cooling near the surface as the amounts of aerosols increase. Significant results could be derived from examining energy and general circulation changes which result from atmospheric heating due to a change of the absorption pattern of the solar radiation by dust produced in semi-arid-to-arid regions.

(4) A study of the impact of dust and dust storms on agricultural production would be valuable to economists and the agriculture community.

(5) During the literature survey for this investigation, it was noted that dust frequency reached a maximum in periods of approximately 20 years, i.e., 1890s, 1910s, 1930s, 1950s, and 1970s. Further study is necessary to determine if there is any cyclic nature of dust storms and if they are possibly linked to sun spot cycles.

(6) Correlations between duration of different wind speeds and visibilities during blowing dust should be examined to improve dust forecasting.

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# APPENDIX A

## LIST OF STATIONS USED IN THIS STUDY

| STATION | IDENTIFIER |
|---|---|
| Dalhart, Texas | DHT |
| Amarillo, Texas | AMA |
| Childress, Texas | CDS |
| Abilene, Texas | ABI |
| Midland, Texas | MAF |
| Lubbock, Texas | LBB |
| Mineral Wells, Texas | MWL |
| Plainview, Texas | PVW |
| Wink, Texas | INK |
| San Angelo, Texas | SJT |
| Sheppard AFB, Texas | SPS |
| Dyess AFB, Texas | DYS |
| Reese AFB, Texas | REE |
| Carswell AFB, Texas | FWH |
| Robert Gray AAF, Texas | GRK |
| Webb AFB, Texas | BGS |
| Hobbs, New Mexico | HOB |
| Tucumcari, New Mexico | TCC |
| Carlsbad, New Mexico | CNM |
| Roswell, New Mexico | ROW |
| Las Vegas, New Mexico | LVS |
| *Clovis AFB, New Mexico* | CVS |
| Trinidad, Colorado | TAD |
| Liberal, Kansas | LBL |
| Garden City, Kansas | GCK |
| Dodge City, Kansas | DDC |
| Gage, Oklahoma | GAG |
| Hobart, Oklahoma | HBR |
| Ardmore, Oklahoma | ADM |
| Oklahoma City, Oklahoma | OKC |
| Altus AFB, Oklahoma | LTS |
| Ft Sill, Oklahoma | FSI |
| Vance AFB, Oklahoma | END |
| Tinker AFB, Oklahoma | TIK |

# APPENDIX B

## ANTECEDENT PRECIPITATION INDEX (API)

The Antecedent Precipitation Index (API) was used as a quick, objective method for estimating the moisture condition of the soil. The index was computed on a daily basis by multiplying the index for the previous day by 0.90. The amount of observed rain that occurred for any day was added to the index. Calculations were begun by assuming an initail index of the normal 10-day total rainfall for the individual locations involved and time of year. After the daily API has been calculated for several weeks, the computed value closely approximates the actual value.

McQuigg (1954) points out that the API gives good results over the eastern and central United States. Values other than 0.90 have been suggested and might give better results for a particular area and soil type.

# VITA

Marshall C. Pollard was born in Salt Lake City, Utah, on 7 April 1945, to Frank G. and Louise A. Pollard. He attended the primary and secondary school systems of Salt Lake City, Utah, and graduated from Granite High School in 1963.

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